

NASA Technical Memorandum 104116

11N-71
20330
P-163

AN ULTRASONIC TECHNIQUE TO MEASURE THE DEPTH OF
BURN WOUNDS IN HUMANS

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JUNE 1991

(NASA-TM-104116) AN ULTRASONIC TECHNIQUE TO
MEASURE THE DEPTH OF BURN WOUNDS IN HUMANS
(NASA) 163 p CSCL 20A

N91-27910

Unclass
G3/71 0026390



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

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SUMMARY

Using an ultrasonic technique, the depth of burn wounds in humans to a resolution of better than 60 microns were measured. Measurements using this technique were taken on patients with scald burns (female, Negro, 30 years old), flame burns (male, Negro, 57 years old), and chemical burns (male, Caucasian, 30 years old).

Measurements were taken on the burn wound and also at an equivalent site in healthy tissue. Comparison of the data from the burn wound and the equivalent site permitted an evaluation of the depth of the burn wound. On this basis a classification of the wounded area was made and compared with the diagnosis and findings of the burns unit medical staff at the Medical College of Virginia (MCV).

Several examples of the ultrasonic data are given in this paper. The depths are based on a sound velocity of 1.5×10^5 cm/sec in all the tissues involved.

Figure 47 shows an ultrasonic measurement from a scald burn wound in a female patient, 30 years old. The left-most reflection comes from the surface. The second reflection comes from the interface between the necrotic skin tissue and viable skin tissue. This indicates that the lesion is 0.60 mm deep, while the skin thickness is 0.90 mm. Based on this, the burn is classified as a deep dermal burn.

Figure 65 shows an ultrasonic reflection from a different location on the scald burn wound on the same patient mentioned above. This was a small area near the center of the wound, noted for its different appearance. The first reflection shows the front surface of the skin. The second reflection indicates the burn interface. The distance between the first and second reflection is 1.1 mm, indicating that in this region the wound becomes a full thickness wound.

The next figures (117 and 121), when considered together, give a comparison of healthy skin and skin from a burn wound. These records were obtained from a 30 year-old male, who had suffered chemical burns to his legs. Figure 121 shows the ultrasonic reflections from the injured leg while Figure 117 shows ultrasonic reflections from a comparable area of healthy skin. From Figure 117, we determine that the thickness of healthy skin is 0.55 mm. From Figure 121 we determine that the wound is a deep dermal wound, with the depth of the burn to be 0.45 mm. Also to be noted is that the thickness, including both necrotic and viable components, is 0.70 mm, indicating the possibility of some edema.

On the basis of these comparative studies, we conclude that the ultrasonic measurements were in agreement with the diagnosis of the burns surgeon and his staff.

Figures 1 through 6, immediately following, are photo records which represent a summary of results.

0 0.5 1.0 1.5mm



Figure 1.- Ultrasonic reflection from a scald burn wound area. Female patient, 30 years of age, admitted March 2, 1987. The first reflection indicates front surface of skin. The second reflection indicates burn interface. The distance from front surface to burn interface equalled 0.60 mm. Total skin thickness as measured from front surface to back surface equalled 0.90 mm. Reflected signal beyond back surface indicates subcutaneous structure.

Ultrasonic data indicates that lesion is a deep dermal burn (second degree) with skin thickness from burn interface to back surface still viable. Measurement made using 15 MHz focused transducer with a 1" sterile gel column.

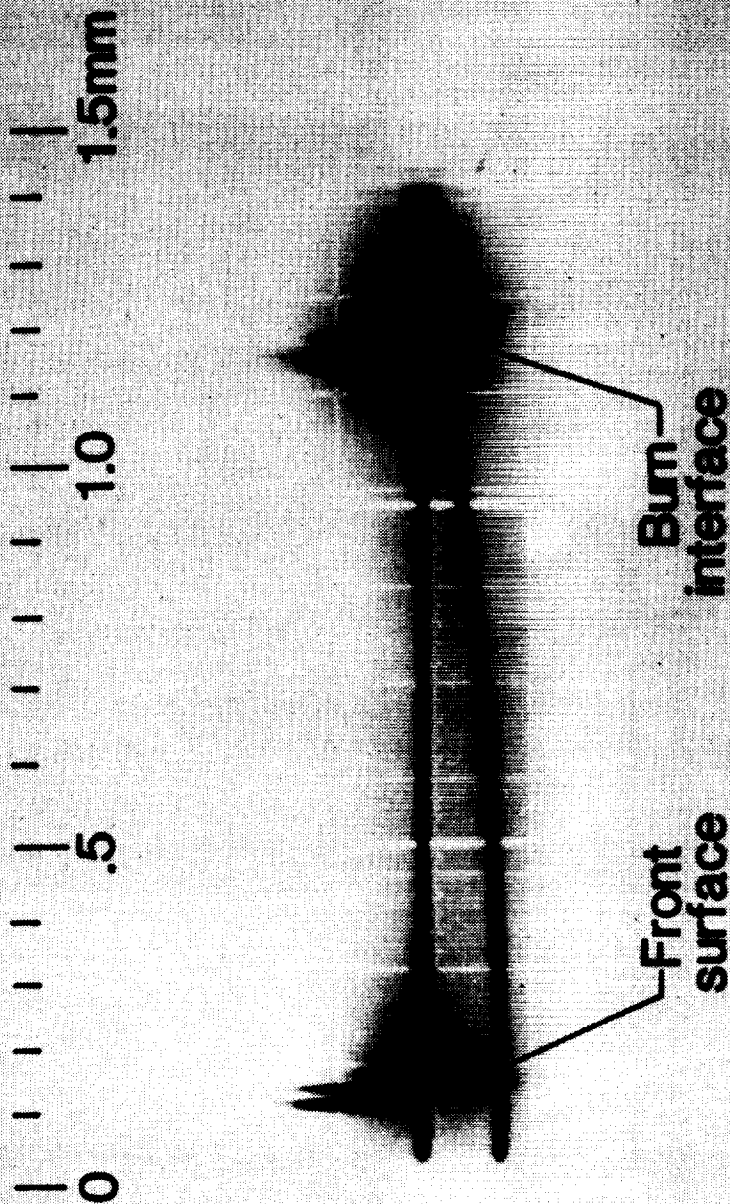


Figure 2.- Ultrasonic reflection from a scald burn wound area obtained from female patient 30 years of age admitted March 2, 1987. Measurement was obtained from center of lesion. The first reflection indicates front surface of skin. The second reflection indicates burn interface. The distance from front surface to burn interface equaled 1.1 mm which indicated a full thickness burn.

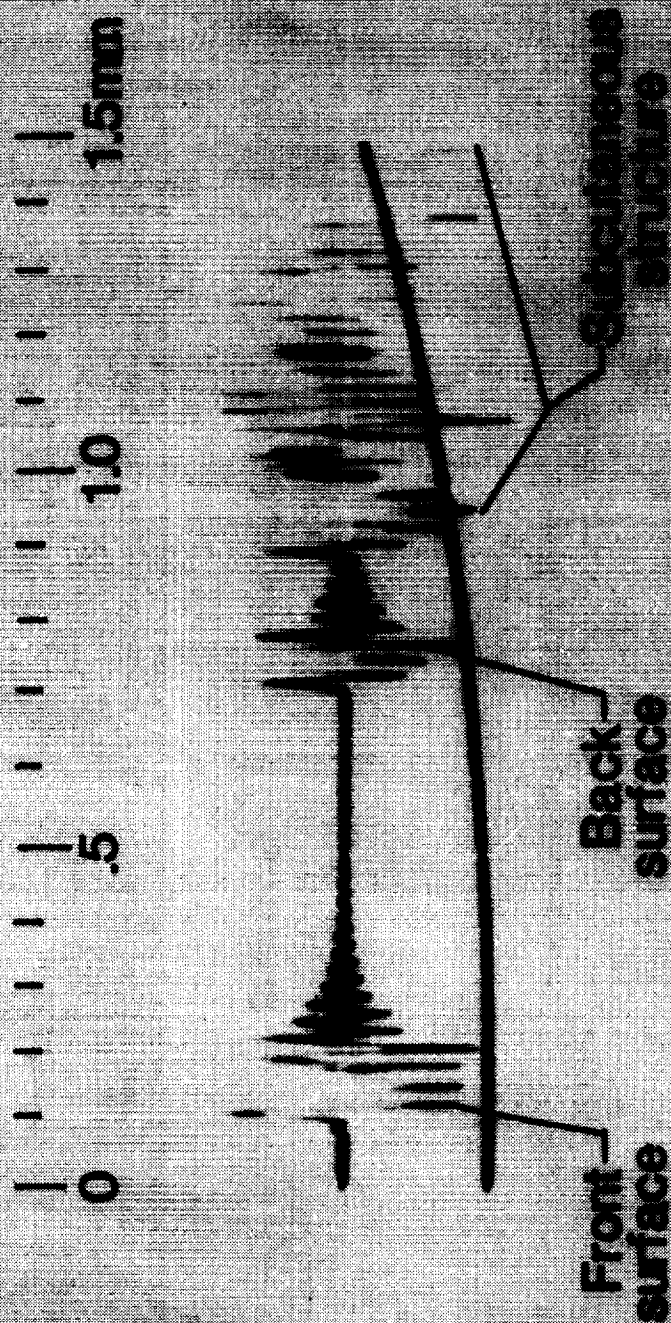


Figure 3.- Ultrasonic reflection from normal skin. Data obtained from comparable areas of noninjured leg of chemical burn patient. (Lesion data shown in Figure 4). Skin thickness of noninjured leg equaled 0.55 mm. Skin thickness of burned area equaled 0.70 mm. Increase in thickness of burned tissue attributed to edema which is characteristic of the chemical burn data obtained in this study.

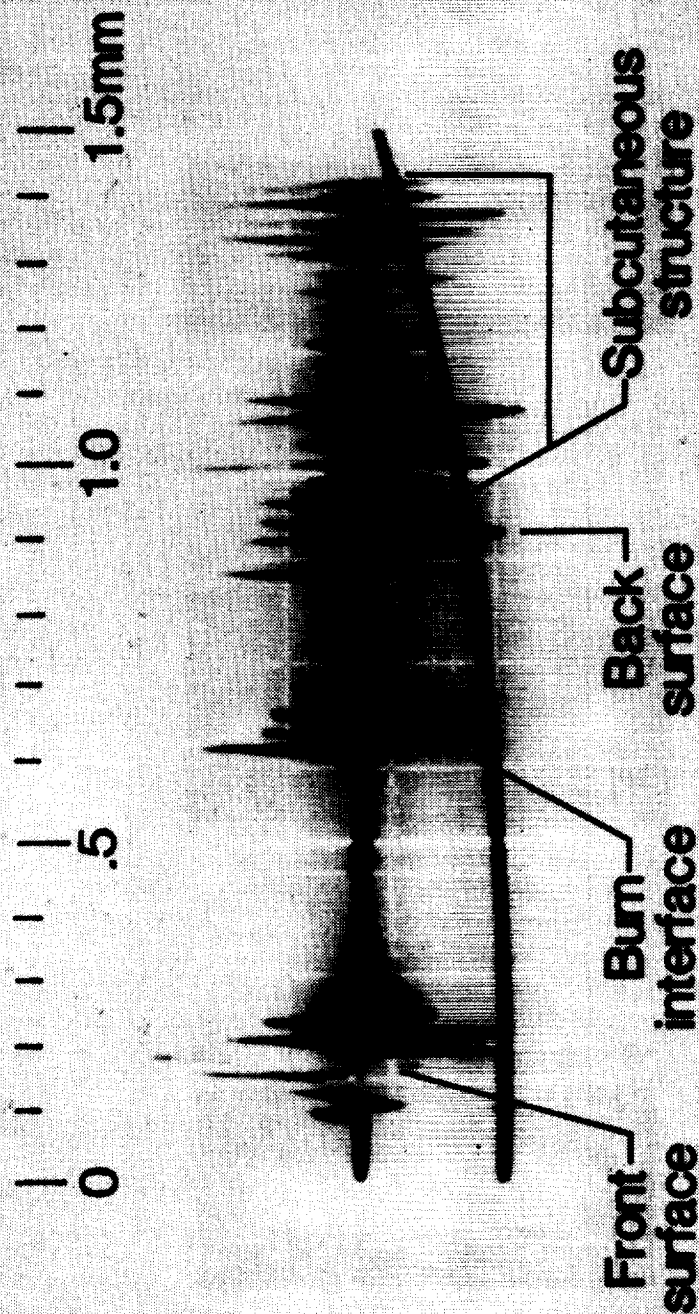


Figure 4.- Ultrasonic reflection from a chemical burn obtained from 30-year-old male admitted March 2, 1987. Skin thickness measured from front to burn interface equaled 0.45 mm. Total skin thickness measured from front to back surface equaled 0.70 mm. Ultrasonic data indicates deep dermal burn (second degree) with one third of skin (0.25 mm) viable.

Figure 5.- Comparison of second degree flame, scald, and chemical burns.

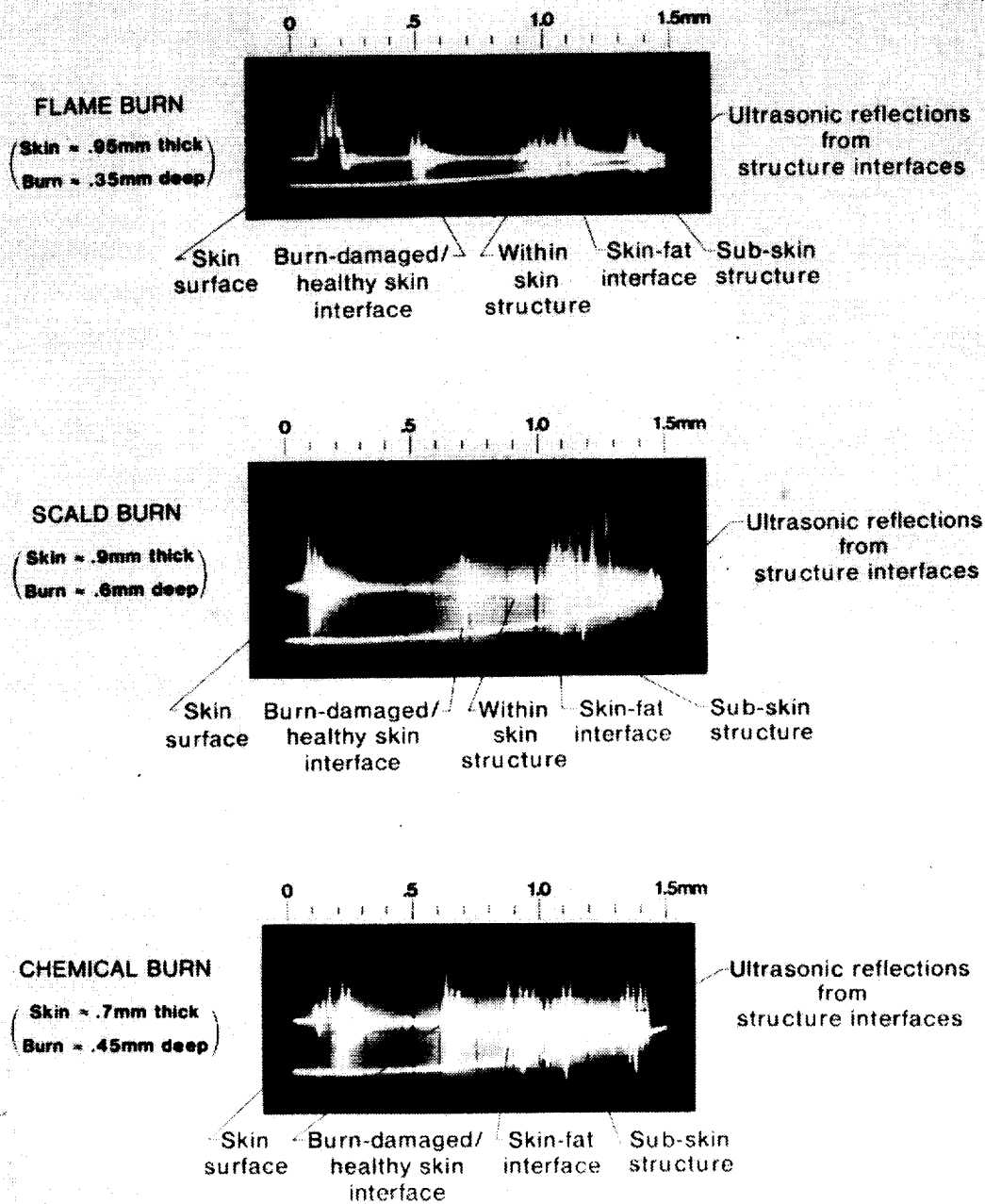
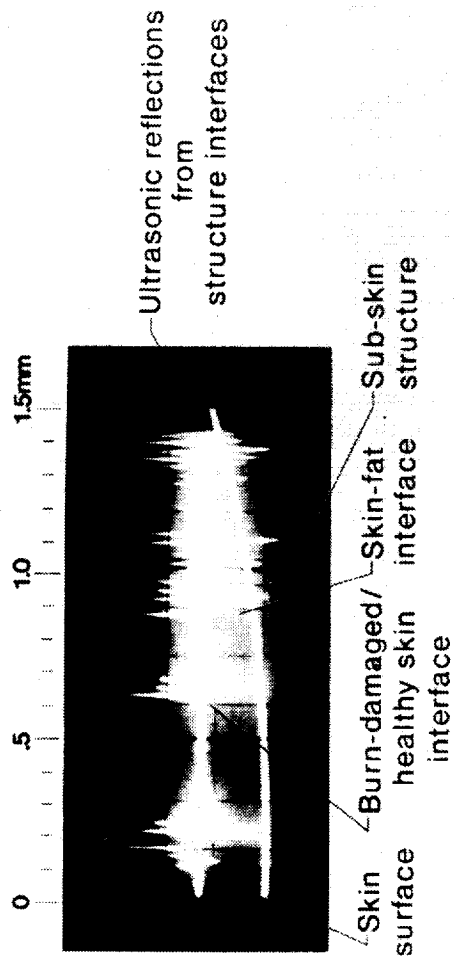


Figure 6.- Display of second degree (dermal, deep dermal) and third degree (full thickness) burns.

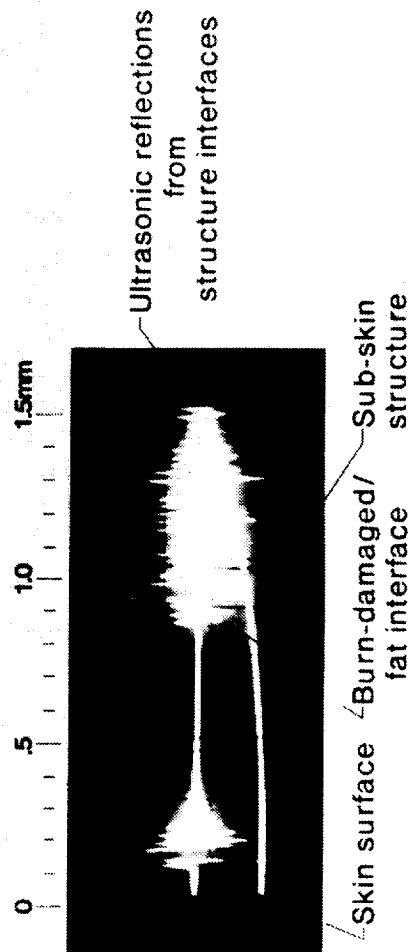
SECOND DEGREE

(2/3 thickness burn
Skin \approx .7 mm thick
Burn \approx .45mm deep)



THIRD DEGREE

(Full thickness
Burn \approx .75mm deep)



I. INTRODUCTION

This report is an interim assessment of the state of an instrument, designed to measure the depth of skin burn injuries in humans. It is to record and document the results of the development thus far and also to describe some impressions and observations to date. It is an attempt to elicit responses from others who have been involved in this study or who have suggestions which would be helpful.

The report has been written in a way that each section contains most of the information needed to read and get some understanding of the material covered by it. As a consequence, the report is verbose, with substantial redundancy on many topics so that key points are not only covered often, but in different ways and in different contexts.

The beginnings of this effort originated with work performed by Dr. John Cantrell and others at Oak Ridge National Laboratories in 1976. The first study was performed on burn wounds inflicted on hogs. The results of that study showed that it was possible to obtain an ultrasonic reflection from a new interface created by the injurious action of the burning iron, kept at 100°C, on the skin of the test animals. The depth of the interface was a function of the time that the burning iron was held in contact with the skin. Thus, by choosing the time of contact one could control the depth of the burn-created interface within the skin. Indeed, it was even possible to inflict a full thickness wound on the animal in this way.

Further analysis of the data taken in that original study permitted Dr. Cantrell to identify the probable cause of the burn-created interface. By examining the dynamics given by his burn model, he could determine that the temperature of necrotic-viable skin interface always reached 65°C, regardless of the depth. This and other facts led him to conclude that the reflection from the necrotic-viable skin interface was caused by a crystalline-amorphous phase transition of the collagen in the necrotic region, caused by the effects of heat from the burning iron on the skin tissue. This work led to an invited presentation given to the International Meeting on Burn Injuries sponsored by NIH in 1983.

Since 1983, the development of an instrument which would be useful in the measurement of skin-burn depth in humans has proceeded. The present instrument design has been tested in animal studies at MCV, where the ultrasonically measured burn wound depth has been compared to that obtained from histological measurements. The agreement between these two techniques was encouraging enough to plan some studies of burn wounds in humans. This study is now ongoing at the burns center at MCV, under the direction of Dr. B. W. Haynes and his associates.

II. ULTRASONIC REFLECTIONS AND THE BURN WOUND

Whenever ultrasound encounters a discontinuity in this medium of its propagation, some of the energy is reflected. In undamaged skin the most prominent reflections occur at the water-front skin interface and from the more distal, dermis-fat interface, water being used as the coupling medium between the transducer and the skin surface. Other less prominent reflections occur from other structures

and interfaces within the skin (one can often observe a reflection from the epidermis-dermis interface, for example). These reflections are predicted from the laws of physics as applied to wave motion of sound in a medium, and are quite analogous, for example, to the reflections of light from the interface between glass and air.

Consider a medium in which ultrasound is propagating. A significant property of the medium is called *impedance*. It is the product of sound velocity and the density of the medium.

$$Z = \rho v \quad (1)$$

where

Z = the impedance of the medium
 ρ = the density of the medium
 v = the velocity of sound in the medium

Variation in either of these quantities can change the impedance of the medium. As long as the impedance of the medium remains constant, however, the ultrasound will travel through it, without reflection, just as light travels, unimpeded, through air.

Whenever there is an abrupt change of the impedance in the path of the ultrasound, some energy is reflected, just as light is reflected from the glass-air interface. The ratio of the amplitude of the reflected ultrasonic wave to the amplitude of the incident ultrasonic wave can be predicted from the equation

$$A_r / A_i = (Z_2 - Z_1) / (Z_2 + Z_1) \quad (2)$$

where

A_r = the amplitude of the reflected wave,
 A_i = the amplitude of the incident wave,
 Z_1 = the impedance of the first medium,
 Z_2 = the impedance of the second medium.

If one can measure the sound velocities and the densities of the two media, one can predict the reflection factor, $(Z_2 - Z_1) / (Z_2 + Z_1)$. Using this and knowing the amplitude of the incident wave, one can calculate the amplitude of the reflected wave.

Ultrasonic Reflections From Viable Skin

Consider what happens to the ultrasound as it encounters and travels through viable skin tissue. Assume that the ultrasound impinges on the skin surface after passing through water. Some of the sound is reflected from the interface between the water and the front surface of the skin. Using values for impedances, one finds that the reflected wave amplitude is in the neighborhood of 1/10 of the initial amplitude. The rest of the sound wave continues traveling through the skin.

Some reflections can occur from the various structures within the skin. In general, these reflections are small, and, except for a weakening of the ultrasound, are negligible. But when the ultrasound impinges on the dermis-fat interface, another major reflection occurs. (This reflection is slightly less than the

reflection from the water-skin interface). This results in a sequence of reflected ultrasonic pulses which are of near equal height, neglecting the effects of scattering and other losses which attenuate the ultrasound. At the receiver, the two reflected pulses are received. The time interval between them is the (round-trip) time necessary for the ultrasound to travel into and back through the skin. By knowing the velocity of sound in skin, one can determine the thickness of the skin by using the relationship,

$$X = Vt/2 , \quad (3)$$

where

X = skin thickness
V = velocity of sound in skin
t = time interval between the two pulses.

Reflections From Necrotic Skin Interfaces

When skin suffers a burn injury, there is a change in the impedance of the region between the front surface and the necrotic-viable skin interface. We believe that this change is caused by the change in the density of the necrotic region. We believe that the density change occurs because of the uncoiling of collagen and effects associated with it. Now we have two regions of different acoustic impedance within the skin itself. Consider an ultrasonic wave impinging on the skin surface. A large reflection (approximately 1/10 of the original amplitude) occurs from the water-necrotic skin interface. Another large reflection (approximately 1/10 of the amplitude of the wave reaching the interface) occurs from the necrotic-viable skin interface. The third major reflection occurs at the dermis-fat interface (approximately 9/100 of the amplitude of the wave reaching this interface). This gives us a sequence of three relatively large pulses, where the viable skin thickness can be calculated by:

$$X = V (t_3 - t_2)/2 \quad (4)$$

where

$(t_3 - t_2)$ = time interval between the second and third received pulses

In addition to the major pulses mentioned above, other structures are more apparent in necrotic skin tissue. This is caused by the formation of sub regions, each with a slightly different impedance. The smaller reflections from the irregularly shaped boundaries between these subregions can scatter substantial energy from the ultrasonic wave, making it necessary to apply special techniques in order to preserve the relative size of the reflections. These reflections also can be used to confirm the identity of the necrotic region, since the viable region will not cause as much scattering between the second and third pulse.

In summary, one expects the instrument to display three reflections coming from a partial thickness burn wound:

Reflection 1 from the water-necrotic skin interface;
Reflection 2 from the necrotic skin-viable skin interface; and
Reflection 3 from the dermis-fat interface.

Between reflection 1 and reflection 2, one would also expect to see more scattering (small reflections resulting in degradation of signal strength) than between reflections 2 and 3.

For full thickness burn wounds one would expect to see two reflections: one from the water-necrotic tissue interface, and the other from the necrotic dermis-fat interface. Also, there will be substantially higher scattering of ultrasound than one finds in uninjured skin.

III. THE INSTRUMENT: DESIGN GOALS

The purpose of the instrument is to faithfully display the results from the echo sequences mentioned above. The instrument must also have the capability to make permanent copies of the output for records. Provisions for adding specialized functions to optimize the display and its interpretation was also considered important. Factors affecting the design of the unit are covered below. Instrument operating instructions are covered in Appendix B.

Frequency Response and Resolution

Typical medical ultrasound machines work in the frequency range from 1 to 10 MHz, and their resolution is inadequate for this application. Consequently, a special unit had to be designed for this study. Therefore, it was decided to design a unit whose electronics, including the display oscilloscope, had a frequency response to at least 60 MHz, which corresponds to a resolution in skin thickness of approximately 26 microns (0.026 mm), much more than needed in this study. This choice of frequency response also assured that erroneous results would not be caused by slow electronics. The unit selected was an A-scan pulse-echo design with high resolution, where the displayed characteristics were determined only by the characteristics of the burn wound and the frequency of the ultrasonic transducer.

By choosing a modular approach, each module could be designed so that its function was optimized for its specific purpose. Moreover, various types of signal conditioning could be added more easily. Each module was functionally analyzed to assure that its contribution was adequate. Some modules were commercially available; the receiver chosen was a modified Metrotek MR-106, with a Metrotek PR-106 pulser-preamplifier-line driver, the power source plug-in chassis module was chosen from the Tektronix TM-500 series. The other modules had special functions, and were to be designed and built in-house.

Factors Affecting Transducer Selection

The resolution of the instrument directly depends upon the frequency response of the transducers selected for the study. In general, the higher the frequency of the transducer, the better the resolution. With increased frequency, however, comes a greater amount of reflected and scattered waves from structures in the skin. At the higher frequencies these structures can give reflections which can actually interfere with the measurement of skin burn depth. One of the goals of this project

was to determine the optimum frequency of the transducer to determine skin burn depth in humans. As a starting point, it was thought that the transducer frequency should be able to resolve 0.1 mm, which corresponded to a frequency of approximately 15 MHz and transducers of 15, 20, and 25 MHz construction were chosen.

Another issue was the fact that most burn wounds occurring in humans would likely result in an uneven and irregular necrotic-viable skin interface. It was believed that focused transducers might give a better performance than the unfocused ones, since focused units can detect uneven interfaces better than the unfocused units. Consequently, 15, 20, and 25 MHz focused transducers were also tried.

Data Display and Recording

A Hewlett-Packard model 1741A storage oscilloscope was chosen as the readout device. Its fast rise-time was assured by its 100 MHz frequency response. It can store a trace for a time sufficiently long that a photographic record can be obtained by using a conventional oscilloscope camera. The camera used was a Polaroid unit onto which a special bezel was attached. While somewhat awkward and time consuming to use, it works reasonably well.

Signal Conditioning

Transducer selection.- As stated earlier, there are two or three major signals to display for the measurement of skin burn depth. Competing with these are reflections coming from other structures and interfaces within the skin. The first step in good signal conditioning is the appropriate choice of transducer frequency. Good results were obtained from the 15 MHz damped focused (1-inch focal length) transducer. While plenty of scattered reflections occurred, it appeared that the reflections of interest were sufficiently strong. There seemed to be no ambiguity in selecting the significant reflections. The other focused transducer frequencies also worked well. For many applications, the 25 MHz transducer was superior, but it was slightly more difficult to obtain and hold good alignment in the water bath with this unit.

Gain.- The gain of the amplifier ranges from -10 dB to +60 dB, and is switch selectable in 1 dB increments and provided enough range for all of the time-gain measurements to date. Typical gain settings are in the range of 47 dB. This achieves adequate sensitivity of the instrument to the reflections returning from the burn wound, and enough gain to offset two other signal conditioning options that had to be built into this instrument; reject, and time-gain compensation.

Time-gain compensation.- A feature that is essential to this instrument is the presence of time-gain compensation circuits. Because much of the energy of the high-frequency ultrasound is lost as it traverses the skin, a way must be found to restore the energy to the original levels. Under certain conditions, the dermis-fat interface reflection can be as low or lower than some of the early scattering reflections. To compensate for the loss of ultrasound, a circuit was devised to increase the gain of the instrument exponentially during the time interval of interest. (This is equivalent to turning up the volume of a TV set in one millionth of a second). We developed a special circuit for this project, since one that would operate at 60 MHz did not exist.

The heart of this unit is a high speed multiplier with a 60 MHz frequency response and a dynamic range of 60 dB. The amplified signal is multiplied by an amount determined by the voltage on the control input. This voltage is generated by an exponential ramp generator to provide the compensation needed. The characteristics of the ramp are adjustable on the front panel, and include starting gain (near gain), maximum gain (far gain), and exponential adjust (intermediate gain).

The triggering of the exponential ramp is caused by the first-received pulse, which is the reflection from the water-skin interface. The ramp is generated for a period of about 3 ms, and is then cleared for the next pulse arrival. The same trigger which starts the ramp is also applied to start the oscilloscope traces. A delay of about 60 nanoseconds is inserted into the signal path to the oscilloscope in order to assure that the water-skin interface reflection is completely displayed on the oscilloscope.

Reject-level cutoff.- After a pattern has been formed on the screen and the time-gain compensation has been set to bring the dermis-fat interface reflection to the level of the water-skin interface reflection, one is left with a number of reflections that are inconsequential to the measurement. To aid the operator, a reject adjustment can be used to remove all but the significant reflections from the display. The result is an oscilloscope trace which is easier to interpret.

The reject is accomplished by providing a back bias to a pair of Schottky diodes which are used in a full-wave configuration to rectify the signal. The back bias requires that only the portion of signal levels which are larger than the back bias will be displayed. The detector filter is designed so that the operator can smooth out the pulses to obtain a more uniform display. It is an R-C coupled diode circuit which has a fast rise time and a slower decay time, thus minimizing any effects on the display resolution.

High pass filter.- This adjustment can aid if there is a tendency for part of the signal pattern to 'float' above the baseline. In general, however, this control has little effect on the output since all of the transducers used are nearly out of the range for this adjustment. If, for some reason, one uses a 10 MHz transducer, the adjustment may be helpful.

RESULTS: ANIMAL AND HUMAN STUDIES

With the permission and assistance from Dr. Diegelmann and the staff of MCV, the instrument was used to repeat the measurements of burn depth in hogs as obtained by Dr. Cantrell and colleagues for the original Oak Ridge study. In particular, the ultrasonic results were compared to histologic data on the same series of burn wounds inflicted on the hog. (The results of this study have been summarized in another report, and have been included as Appendix C of this report).

The agreement between the histologic data and the ultrasonic data was certainly good enough to suggest that the ultrasonic technique be tried on human patients.

Under the direction of Dr. Haynes and his colleagues, measurements on burn wounds in three patients who had been admitted to the Burns Unit at MCV were obtained. One was a scald burn wound from boiling water falling on the patient's feet. Another was a chemical burn wound on legs from prolonged contact to cement dust. The third was a flame burn wound on the patient's back. Data were taken on the patient with the scald burn wounds three times over a 9-day period.

For each data set taken, control measurements were made on a region of skin that was in a healthy, undamaged area. This was used as a comparison with data obtained in the wound region. A Polaroid photograph of the wound was marked to denote the (approximate) locations where data was taken. On the basis of measurements from photos of the A-Scan display, the burn wound thickness was determined. Supporting photographs used in these determinations have been numbered for reference and are appended to this report.

Scald Burn

March 3, 1987:

Data were taken on the wound on the right foot. Control data were taken at three sites (two on the right and one on the left of the burn site). A sketch was marked to indicate the locations where data were taken. (Photographs of the wounded area were taken by MCV staff). The results of our analysis was that the burn area consisted of mainly second-degree burns, interspersed with small areas of third degree burns.

March 9, 1987:

Data were taken on the wound on the right foot. Control data were taken at one site on the left calf. A Polaroid photograph was marked to indicate the locations where data were taken. The result of our analysis was the burn area consisted of mainly second-degree burns, interspersed with small areas of third degree burns.

March 12, 1987:

Data were taken on the wounds on the right foot. Control data were taken at one site on the right foot. A Polaroid photograph was marked to indicate the locations where data were taken. The result of our analysis was that the burn area consisted of mainly second-degree burns, interspersed with small areas of third-degree burns.

Chemical Burn

March 3, 1987:

Data were taken on the wounds on the right and left leg. Control data were taken at four sites (two each on the right and left leg). A sketch was marked to indicate the locations where data were taken. (Photographs of the wound area were taken by MCV staff). Analysis indicates that the burn area consisted of mainly second-degree burns, interspersed with small areas of third degree burns.

Flame Burn

March 12, 1987:

Data were taken on the right upper back of the patient. Control data were taken on the right side under the arm. A Polaroid photograph was marked to indicate the locations where data were taken. Analysis indicates that the patient had full thickness burns to his back with second-degree burns around the perimeter of the burn wound.

V. TECHNIQUES USED TO ACQUIRE AND INTERPRET THE DATA

Terminology Used

The setup and the operation of the instrument is covered elsewhere in this report (Appendix B). This portion deals with issues which are useful in taking the records. To facilitate the reading of this section, it will be helpful to identify certain terms even though many are covered elsewhere. A record is a photograph of the oscilloscope screen. Data refers to a series of pulses or spikes that appear in a sequence on the oscilloscope screen. The transducer refers to the ultrasonic device which acts both as a sender (like a speaker in a sound system) and a receiver (like a microphone). Focus refers to the fact that the transducer focuses the ultrasound to a point just like a lens can focus a ray of light to a point. Frequency (of the transducer) refers to the predominant frequency emitted by the transducer. It is important because the higher the frequency, the better the instrument can display sharp pulses. (Unfortunately, the higher the frequency, the more detail of skin structures that will be displayed and the additional details can make an interpretation of the record more difficult). A control record is a record made in healthy skin in order to find the approximate location of the spikes or pulses from the front and back surfaces. This is an aid in evaluating the location of two important members of the sequence, the front surface and the dermis-fat interface.

Measurements - the Sequence of Events

Consider that the system is set up and you are ready to begin to take measurements. Moreover, assume that you are measuring the thickness of a deep dermal burn wound. The basic operational sequence of ultrasonic events of the system occurs in the following way: (1) The circuit activates the transducer to send a pulse of ultrasound through a medium, such as water or gel, and into the skin. Then the circuit immediately switches to the listening mode. (2) As the ultrasound encounters the various boundaries or interfaces, each reflects some of the ultrasound back toward the transducer. These reflections form a specific sequence. The first in the sequence is the reflection from the interface between the skin and the medium. The second comes from the interface between the necrotic skin tissue and the viable skin tissue. The third comes from the dermis-fat interface. Other reflections which follow these three arise from subcutaneous structures and boundaries, and are not important in this application. This sequence is received by the transducer and forms voltage pulses. (3) The pulses are displayed on the oscilloscope screen in the same sequence that they were received. The distance between the pulses is proportional to the time difference between receptions.

If the measurement is of healthy skin or in some cases, full thickness wounds, then one will see a sequence of two spikes. The first is the front surface of the skin and the second is the dermis-fat interface. (Besides visual notation, one will notice that the spikes from a full thickness wound will be smaller, with other smaller reflections between the main ones).

Supporting Data Needed

It is important that records be made from not only the burn wound, but also from areas in healthy skin which are either near the wound or from a bilaterally equivalent area that corresponds to the burn site. This, when considered with the burn wound records, will aid in establishing the front and back surfaces. (The machine is set up as covered in Appendix B. It is assumed that the operator is familiar with the controls and their nominal settings). The system is designed so that the transducer face is always 1 inch from the surface of the skin. The cylindrical column attachment is designed so that when it is touching the surface, the transducer is at the correct distance. It is also important that the transducer be kept perpendicular to the surface. **Only when both the perpendicularity and the distance conditions are met will the instrument work properly.**

Data Taking-Waterbath

General Points

Most of the measurements in this report were taken while the patient's wounds were submerged in a tub filled with water. In these cases, the sterilized cylindrical tube was placed on the end of the transducer prior to measurement in order to help us determine the appropriate distance from the wound site as mentioned above. For the most part such an arrangement was an aid in getting the data. At first the tip of the tube did not touch the patient's wound, for fear of causing some pain or discomfort. As time progressed, we actually touched the wound with the tip to assure that the distance was optimal. (Our fear of causing discomfort seemed unfounded, as we could actually apply some light pressure without any complaints).

Measurement Techniques

When ready to make the measurements, the transducer, face pointing up, was lowered until the cylindrical tube filled with water, creating a water column within the tube. The transducer was then put into position to obtain the data, while making sure that no debris or air was trapped in the column.

It was difficult to maintain the transducer perpendicular to the wound surface while operating the instrument. The problem often resulted in less than ideal pulse records because (a) if the operator used the foot pedals, the alignment would change slightly because of operator movement as the foot switches were activated and the pulse heights would be lower than ideal; or (b) if the operator asked for assistance, the time lag between request and execution was sufficient for some misalignment. Sometimes alignment would be adjusted and the patient would move enough to affect the quality of the record (but not its accuracy). Often, however, such movement would ruin the record. On average, it took us approximately 45 minutes per patient to get three or four sufficiently good records using this technique.

Improvements could be made so that the operator could operate the instrument record procedure with a push button on the transducer assembly. This would permit the operator's eye-hand coordination to control the process, and would, depending on the operator, allow for quickest reaction between observing the best pattern and saving its image.

Data Taking With the Gel-Column

The greatest improvement in operation occurred when a gel-filled cylindrical tube was substituted for the water column. Once the gel was properly loaded into the column, the transducer was placed directly on the wound and a measurement could be taken with relative ease. We noticed that it was much easier to use, because in part, the patient was not as apt to move as when he was in the tub. Moreover, it was easier to hold alignment and get the record. We were able to reduce the time necessary to get the records by as much as 60 percent (approximately 15 to 20 minutes). With some practice, the time could probably be reduced further.

Loading Gel Into the Column

Care had to be exercised in loading the sterile gel into the tube. Sterile techniques were followed. The packet of sterile gel was wiped with alcohol and the small end torn off. The torn end was opened to approximately a circular configuration by lightly squeezing the edges. The smaller end of the column was inserted about quarter way into the gel packet. The packet was squeezed from the bottom until the column was filled with the gel to overflowing. The overflow would form a roughly hemispherical shape at the top of the tube. The transducer is placed vertically against this and is slowly pushed into position. The thumb screw is then tightened and the packet is removed just before measurement. More detail for loading is contained in Appendix D.

Since air bubbles will cause reflections, which mess up the timing circuit sequence, it is essential that this process not allow any bubbles in the gel column. This can be accomplished in a number of ways. We always stored the packets vertically, prior to use. During the loading procedure, we kept them vertical. As the gel is squeezed from the bottom, we watched for air bubbles. If they appeared, we squeezed them out the top of the tube. After some practice, we didn't have much trouble with the loading procedure. Nevertheless, if a bubble appears in it, the column must be reloaded until the gel in the tube is bubble-free.

Measurement Techniques

After the instrument was adjusted properly, the packet was removed from the gel-filled column and the transducer-column assembly was placed against the area to be measured. Sometimes it was helpful to place some gel on the skin. Alignment of the transducer-column was made while watching the oscilloscope screen. When a clear pattern emerged on the oscilloscope screen, the image was saved and a record was made.

During the measurement procedure, the gel in the tube would often become mixed with tiny air bubbles. The surface which was in contact with the skin would take on a milky appearance. Sometimes this will lead to false triggering, where the first spike (coming from the skin surface) will be slightly displaced to the right. Such a situation does not affect the accuracy of the data.

If, however, the situation becomes too severe, then the spike from the dermis-fat interface will not be displayed, or the important pulses will become small and distorted. Then the gel in the tube has to be replaced.

Record Interpretation

In order to make a determination of the thickness of the burn wound, the wound records and the control records were examined. It is important at the outset of this section for the reader to realize that the burn wound depth will change from point to point in the wound. With the 15 MHz focused transducer, the area interrogated has a diameter of approximately 0.1 mm (less than the thickness of pencil lead). This means that it will be nearly impossible to measure exactly the same location more than once. Therefore, one should expect some record to record variation even though the records are nominally from the same location.

Other factors can also affect the records. For example, the effects of edema will be evident, especially as healing progresses, and the ultrasound will show this. Taking everything into consideration one can expect variations in relative distances between the pulses from record to record and from day to day.

Interpretation Example: Refer to Figure 9 and 23

In this section, determination of the burn wound depth is demonstrated. This will be done in example form. The records used for this example are a control record (figure 9) and a record of a burn wound (figure 23). It will be helpful for the reader to mark or to tab these two records for easier viewing. The reader should obtain a centimeter scale and a calculator. Figure 9 shows a control record of a scald burn wound, where the control was taken near the wound site. Figure 23 shows a record of the burn wound. The records were taken several days post burn.

One notices several features that the two records have in common. There are two traces on each record. The trace closest to the top (the one with the spikes and wiggles) is the ultrasound trace which is of major interest.

The one below, which looks like a curved line, is the time-gain compensation signal, and is useful because, when adjusted properly, it assures that the major pulses of interest are approximately the same height. However, its display is not needed, unless there are problems, and the instrument settings need readjustment.

One other point about the time-gain compensation needs to be made. Sometimes the record shows a small spike associated with the front surface, and a considerably larger spike associated with the dermis-fat interface. The spike associated with the burn wound appears with other spikes between these two. If a straight edge is placed from the the spike tip from the front surface and the spike tip from the dermis-fat interface, then the spike from the burn interface will most likely be the one closest to the straight edge.

Calculations were made using equations three and four in Section II.

Control Record

Consider figure 9. On the far left are a series of several spikes. This represents epidermal structures. Two spikes in this series stand out as relatively high. The first tall one is the front surface of the skin. The next series of high spikes begin at a distance of 7.69 cm from the front surface spike. (Notice that the distance between major scale marks on the oscilloscope represents

0.2 microseconds). This has a time separation of 0.974 microseconds. Using the fact that the velocity of sound in human skin is 1.56×10^5 cm/sec, we arrive at a skin thickness of 76 mm at the site where the control record was made.

There are other structures shown in the record, but the ones to the right of the second series of tall pulses are not of any concern, since they appear after the reflection of the dermis-fat interface and represent subcutaneous structures. Note also that small pulses are present between the two series. These are most probably due to structures within the skin at the site where the record was made.

Burn Record

Consider figure 23. There are six series of spikes, but one is concerned with the three series which have the tallest spikes. Starting at the far left, the first spike comes from the skin surface. We identify the series that begins 11.75 cm from the spike associated with the front surface as the dermis-fat interface. This corresponds to a time of 1.49 microseconds. Assuming that the velocity of ultrasound in the skin is 1.56×10^5 cm/sec, we get a thickness of 1.16 mm. The tallest series between the first series and the series arising from the dermis-fat interface is what is interpreted as the **burn wound interface**. The other pulses that are seen between the burn wound interface and the dermis-fat interface arise from reflections from cutaneous structures.

The first spike in the series identified as the burn-wound interface series is located 3.3 cm from the first spike in the record. It is also 8.45 cm ahead of the first spike in the series associated with the dermis-fat interface. It can be calculated that the burn wound interface is 0.33 mm below the surface of the wound.

Also, the thickness of viable skin at that point is 0.83 mm from the dermis-fat interface. We conclude that the burn wound at the point where that measurement was made is a second degree burn of thickness 0.33 mm.

It is also noted that the burn wound thickness is substantially larger than the skin thickness at the control site. Assuming that the normal thickness of the skin prior to burning is close to the thickness at the control site, it is concluded that edema is the cause of the difference in thickness. If so, edema accounts for approximately 0.40 mm of the thickness. This would give a swelling of the skin of approximately 35 percent during post-burn healing up to the time that the measurements were made. If one assumes that all of the swelling takes place in the viable tissue, then the swelling is approximately 93 percent of this tissue.

CONCLUSIONS

It is concluded from the data shown here that a high resolution ultrasonic instrument can aid the burns surgeon in measuring, noninvasively, the burn wound depth in humans where the burn wounds have arisen from scalds, chemicals, and flames. In all cases mentioned above, the results from the ultrasonic measurements are in agreement with the diagnosis of the burns surgeon and the outcome of the healing process.

ACKNOWLEDGEMENTS

We wish to take this opportunity to thank the personnel at the Medical College of Virginia, whose cooperation and help made possible the work presented here. Specifically, Dr. Anthony Marmarou served as the liaison between us and the MCV establishment. Dr. B. W. Haynes, head of the Burns Unit, gave observations and insights into the medical aspects of the burn wound. Dr. R. Diegelmann provided the histological sections on the animal studies performed by Dr. J. Nelson. Also, special thanks are due to Ms. Jana Dunbar, who helped with all the laboratory arrangements and photographic documentation.

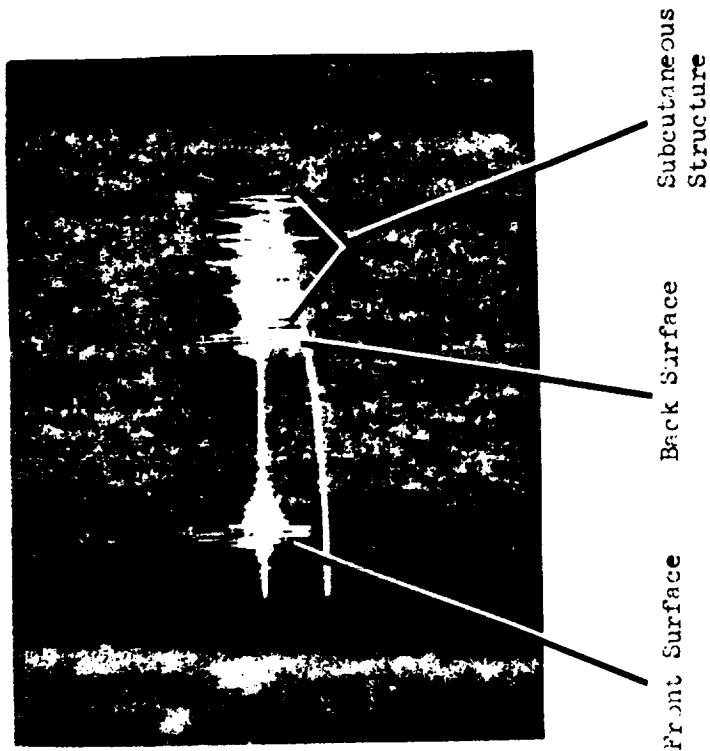
We also thank Dr. Doris Rouse and Mr. Dan Winfield of the Biomedical Applications Team at Research Triangle Institute, whose initial contacts introduced us to the medical and business communities. Especially, we thank the Technology Utilization staff and particularly the staff at NASA-Langley Research Center, Mr. John Samos, Mr. Les Rose, and Dr. Frank Farmer, for their help and encouragement throughout the project. Without their help, this work could not have been accomplished.

APPENDIX A

Photographs and Index



Figure 7.- 8 x 10 of burn locations.



#30B
Focused 15Mhz Xducer

Control-side of right big toe
Skin thickness .70mm

Figure 8.- Control side of right big toe.

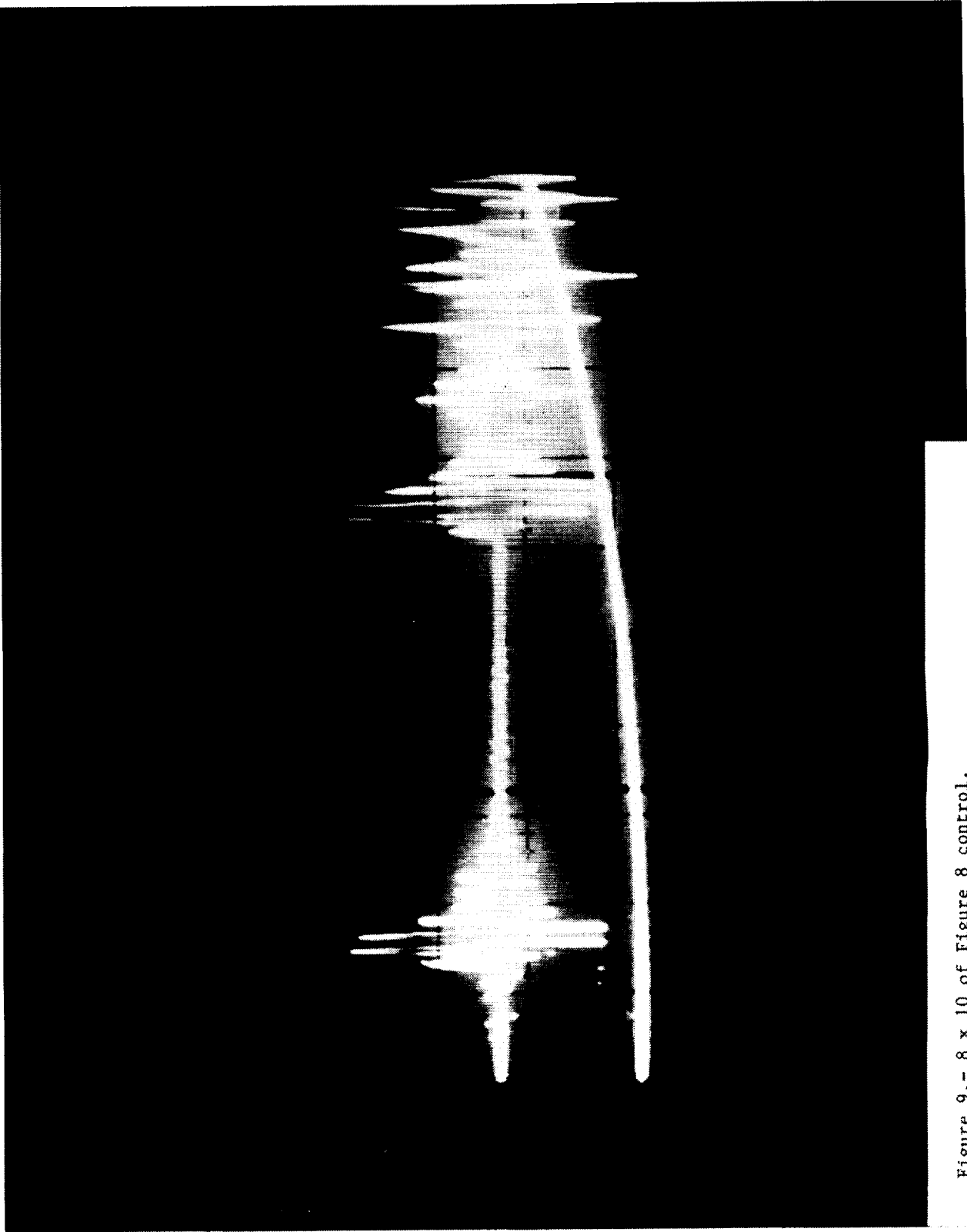
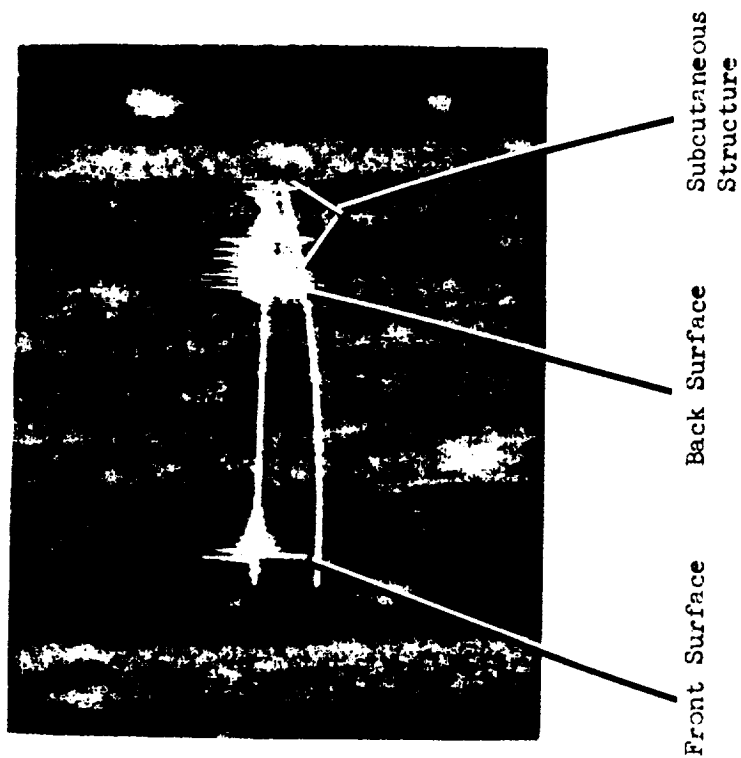


Figure 9.- 8 x 10 of Figure 8 control.

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Control-top of foot (7cm up from 2nd toe & 3cm in from side of big toe)
Skin thickness .95mm

F30B
Focused 15Mhz Xducer

Figure 10.- Control top of right foot.

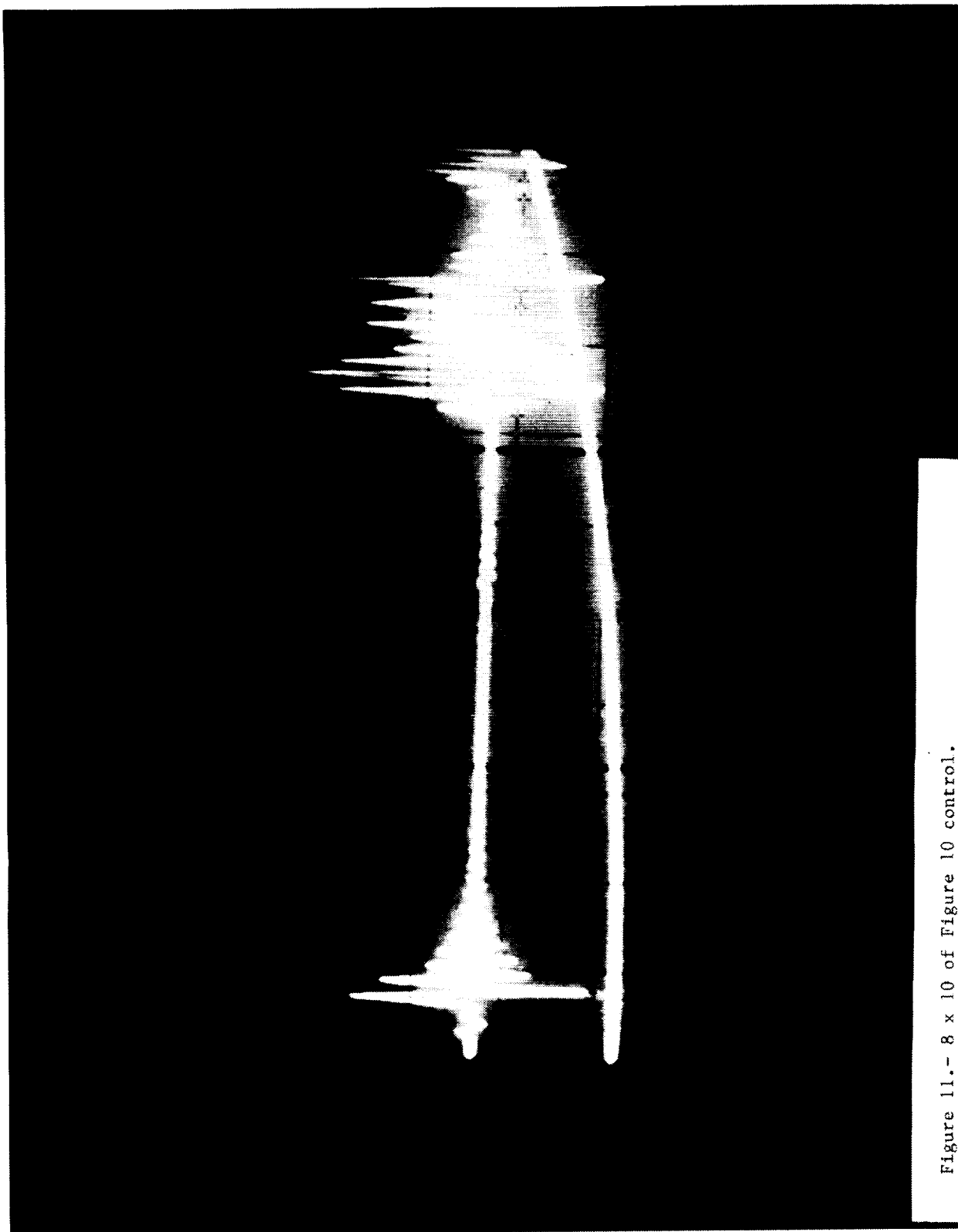
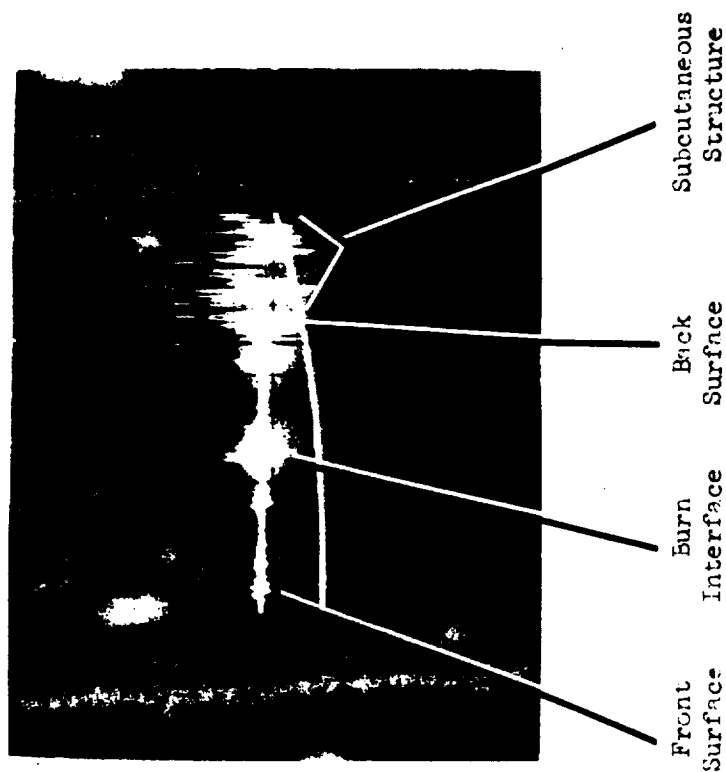


Figure 11.- 8 x 10 of Figure 10 control.

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Right foot burn location 1-2nd degree 1/2 thickness

Skin thickness .95mm

Burn interface .50mm

F30R

Focused 15Mhz Xducer

Figure 12.- Right foot burn location 1.

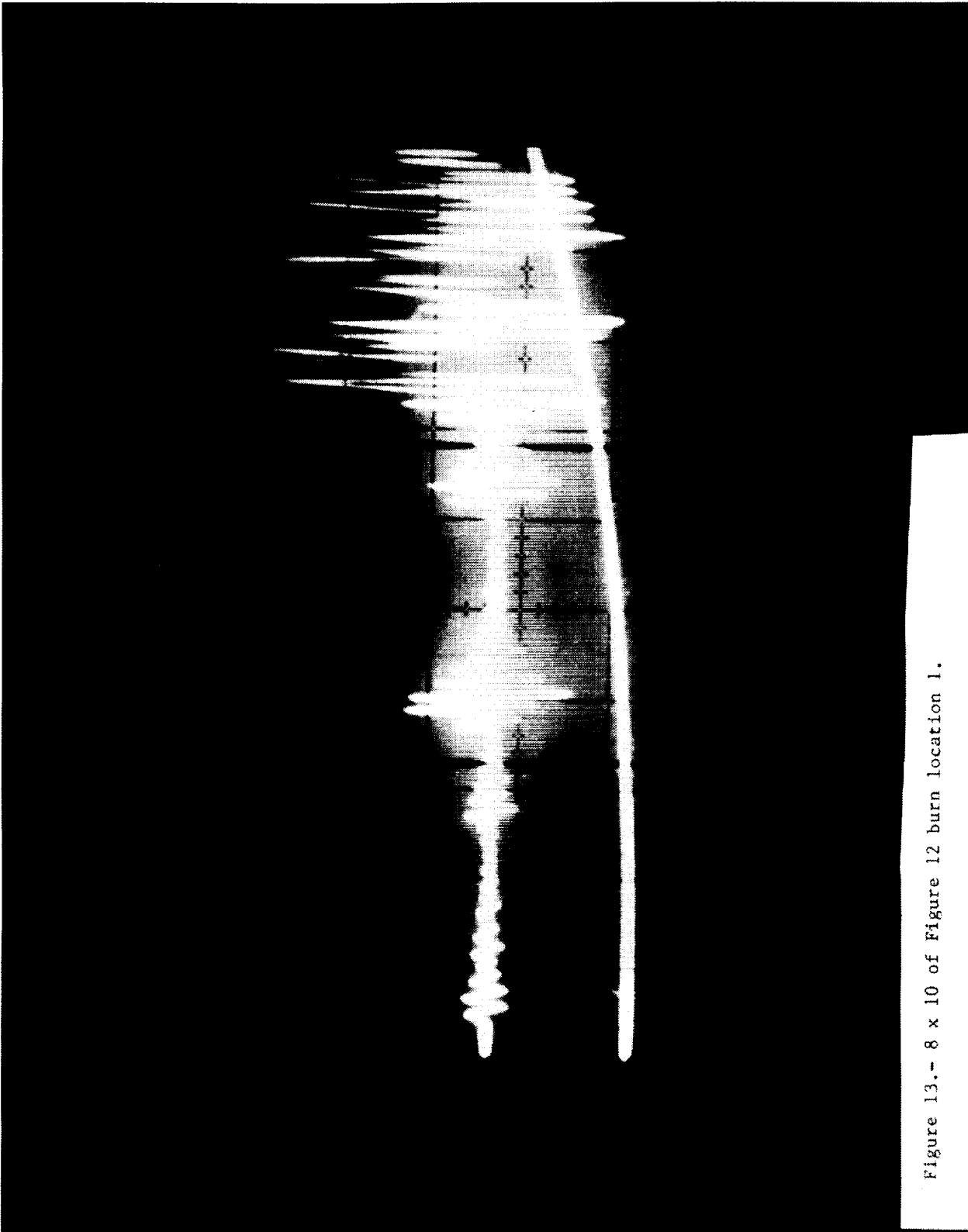
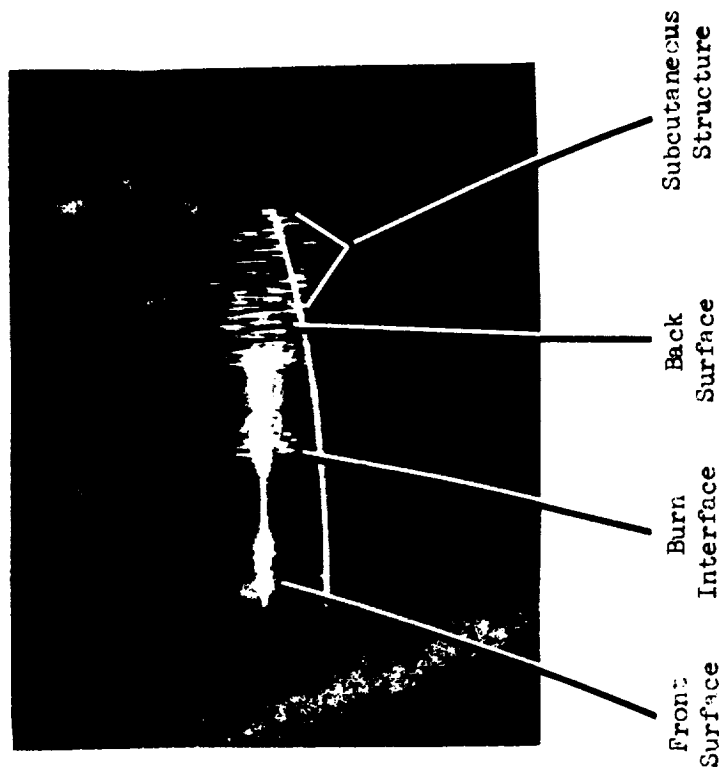


Figure 13.- 8 x 10 of Figure 12 burn location 1.



Right foot burn location 1 - 2nd degree 1/2 thickness

Skin thickness .95mm

Burn interface .5mm

F30B

Focused 15Mhz Xducer

Figure 14.- Right foot burn location 1.

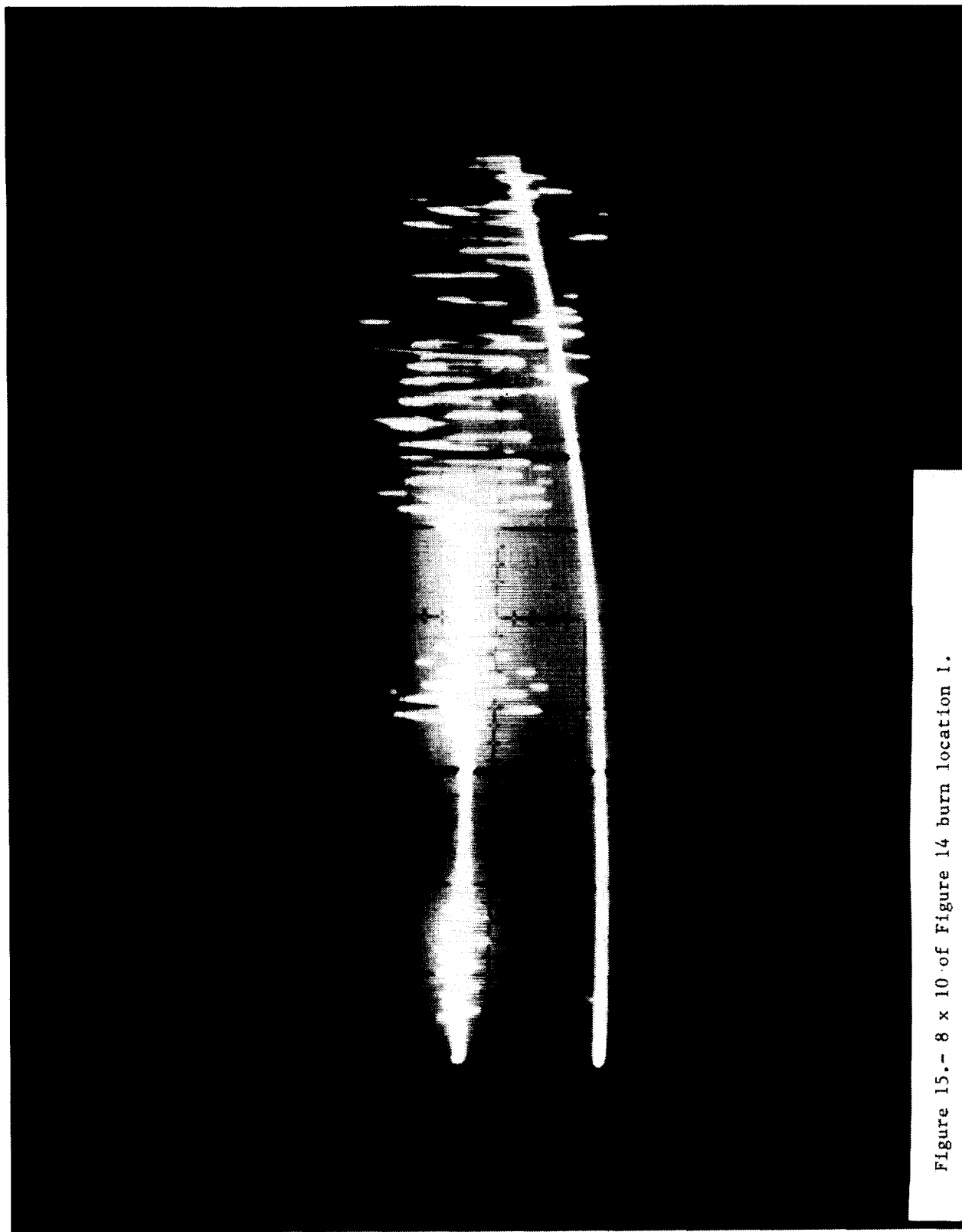
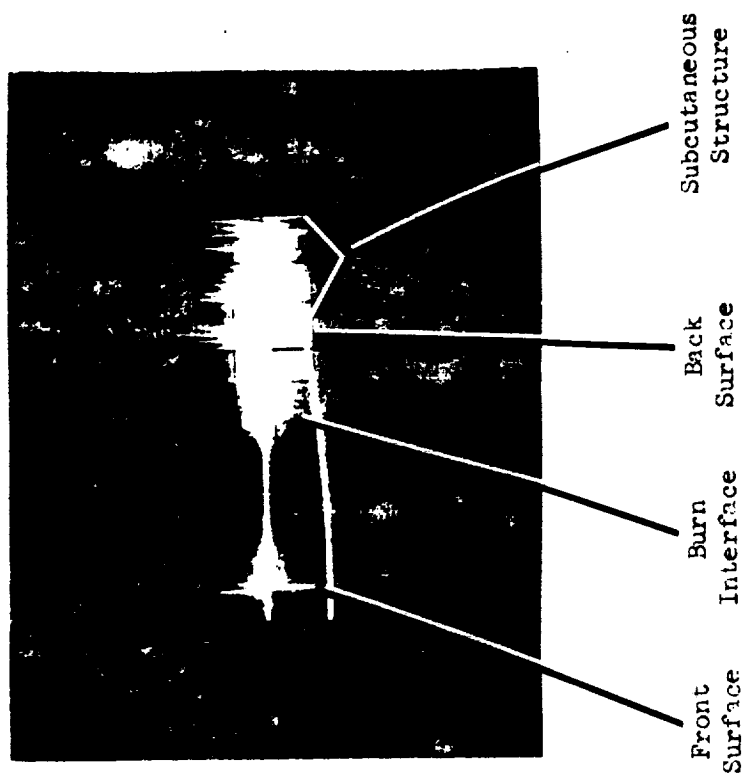


Figure 15.- 8 x 10 of Figure 14 burn location 1.



Right foot burn location 1 - 2nd degree 2/3 thickness

Skin thickness .9mm
Burn interface .60mm

F303

Focused 15Mhz Xducer

Figure 16.- Right foot burn location 1.

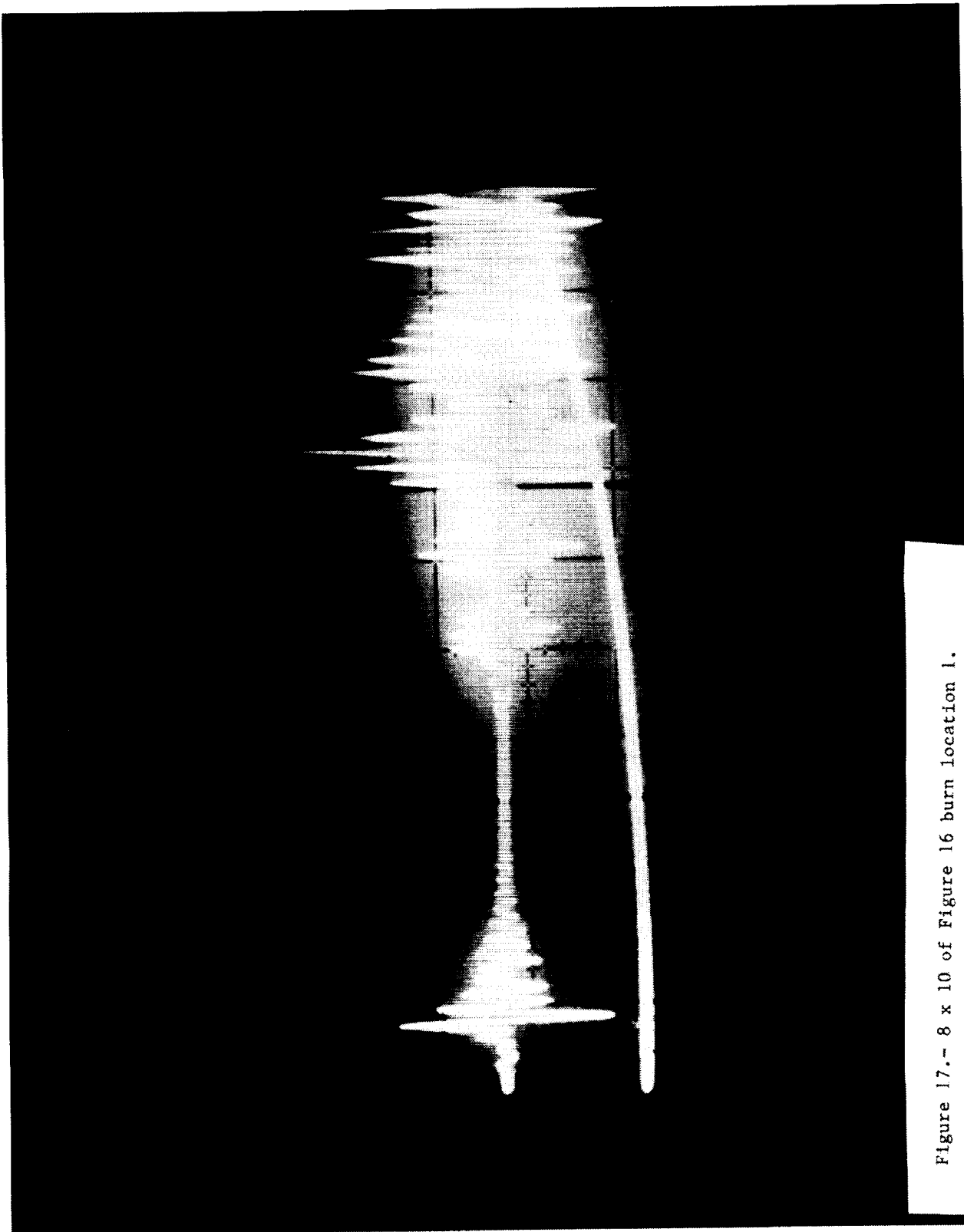
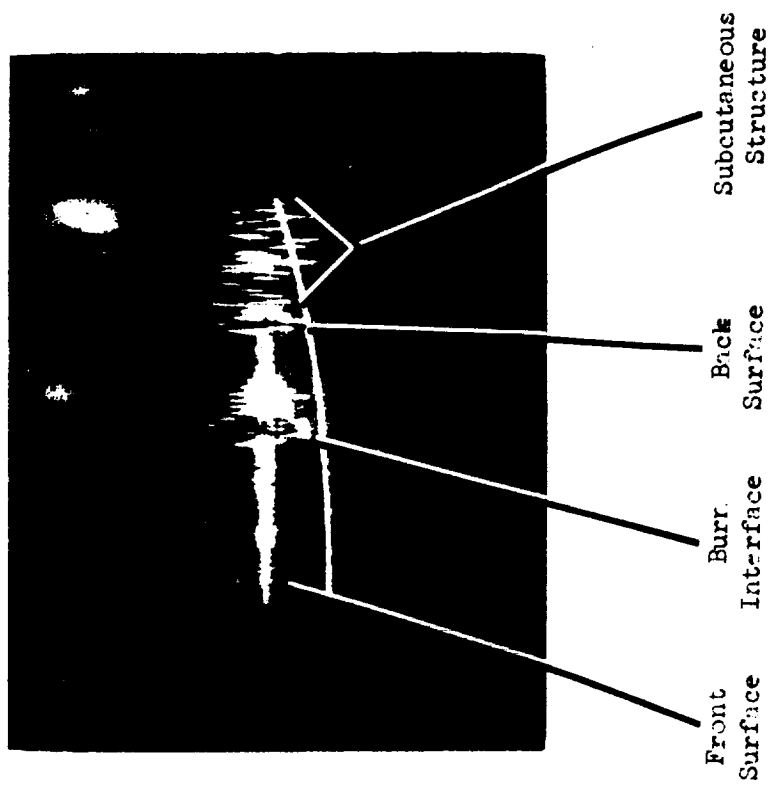


Figure 17.- 8 x 10 of Figure 16 burn location 1.



Right foot burn location 2 - 2nd degree 1/2 thickness

Skin thickness .90mm

Burn interface .55mm

F30B

Focused 15 Mhz

Figure 18.- Right foot burn location 2.

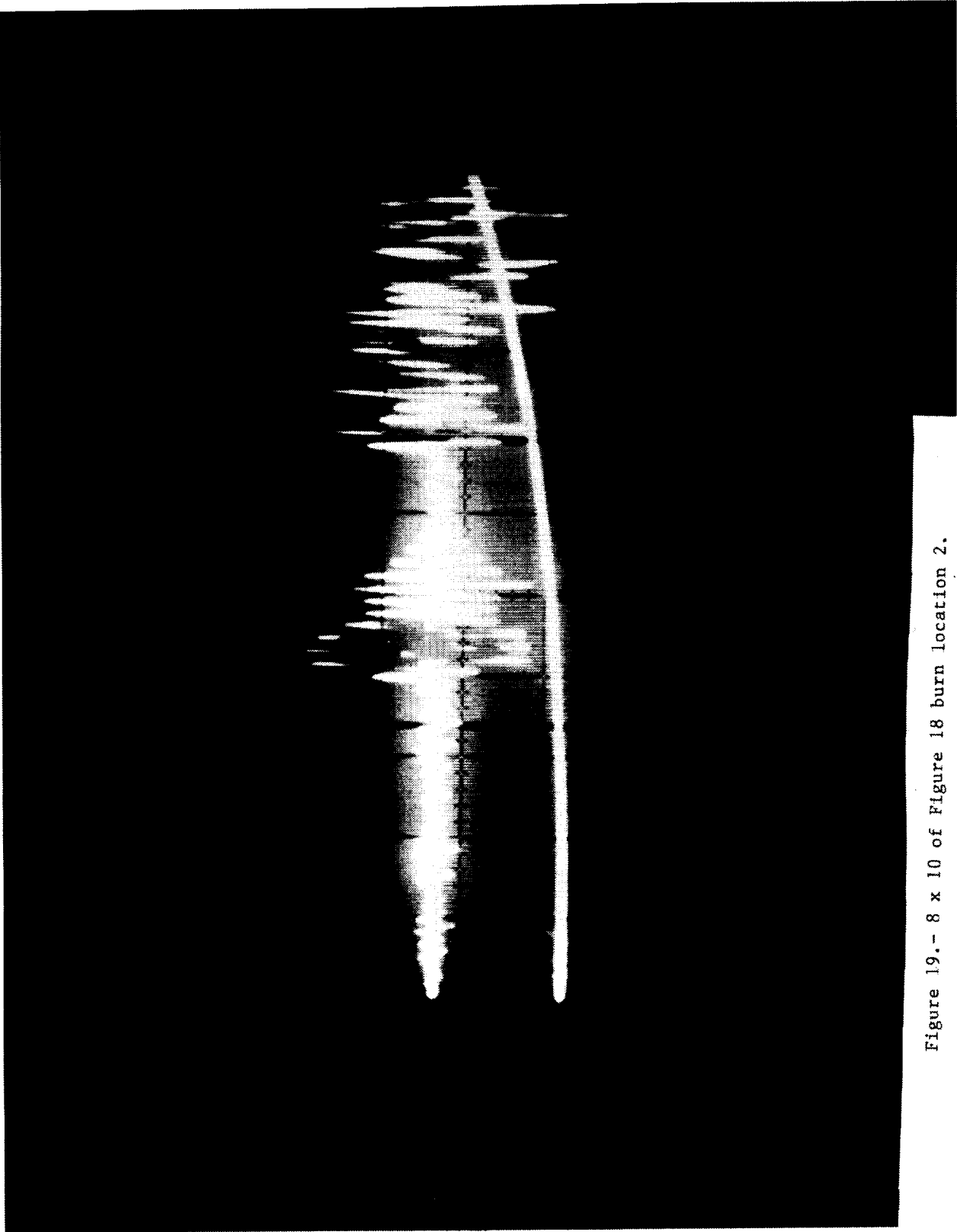
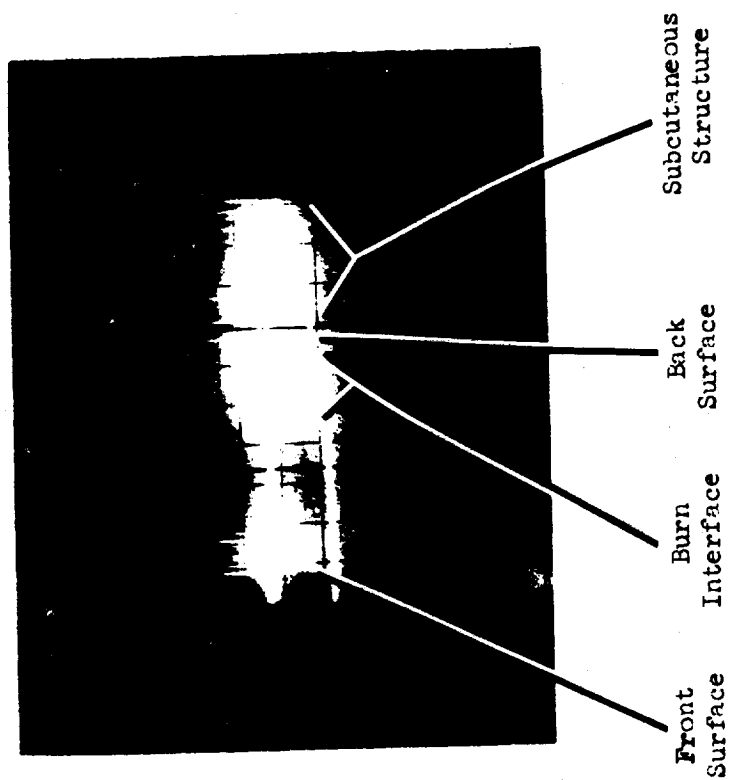


Figure 19.- 8 x 10 of Figure 18 burn location 2.



Right foot burn location 3 - transitional - combination of deep dermal with interspersed 3rd degree

Skin thickness .85mm

Burn interface .7-.85mm

F30B

Focused 15Mhz Xducer

Figure 20.- Right foot burn location 3.

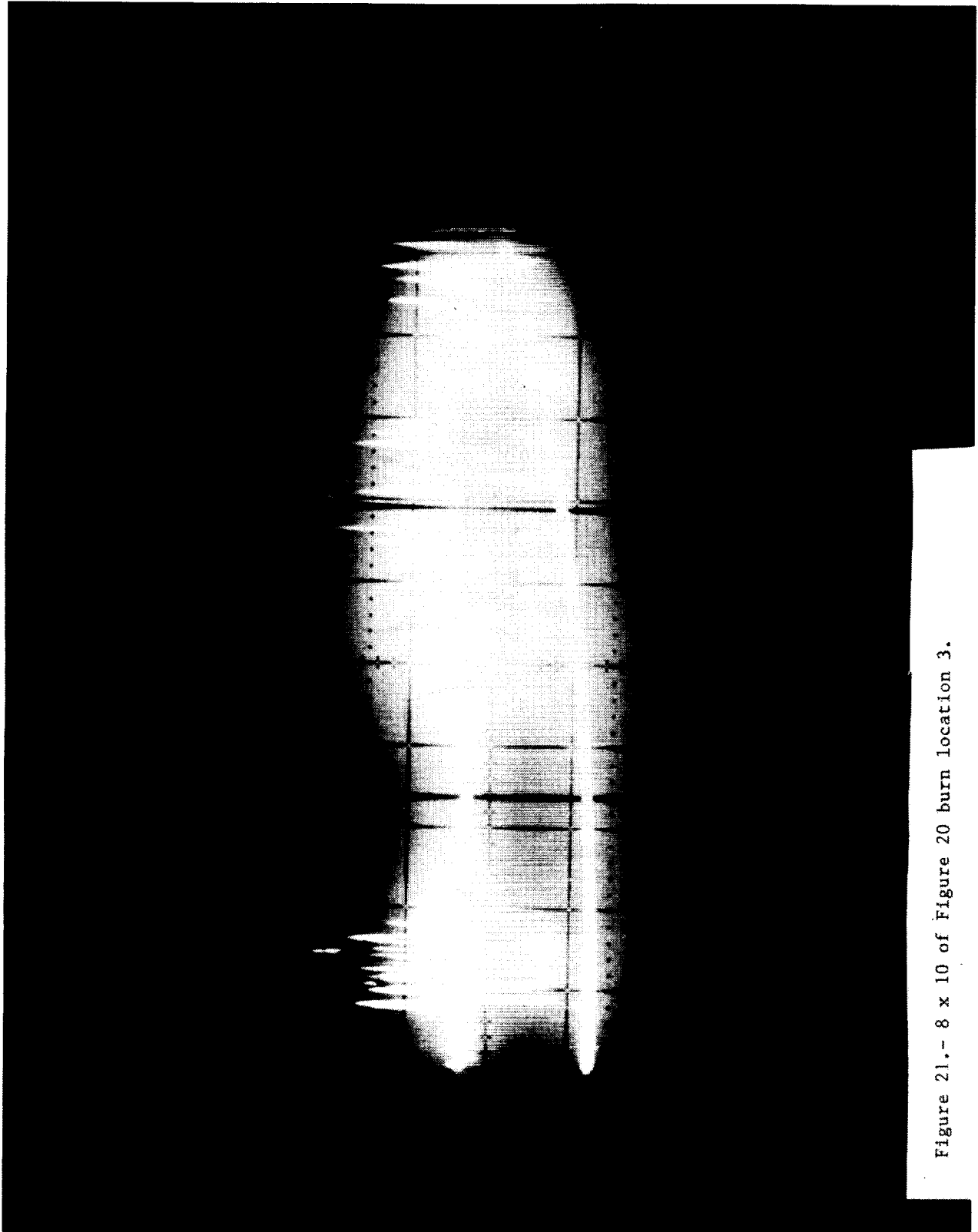
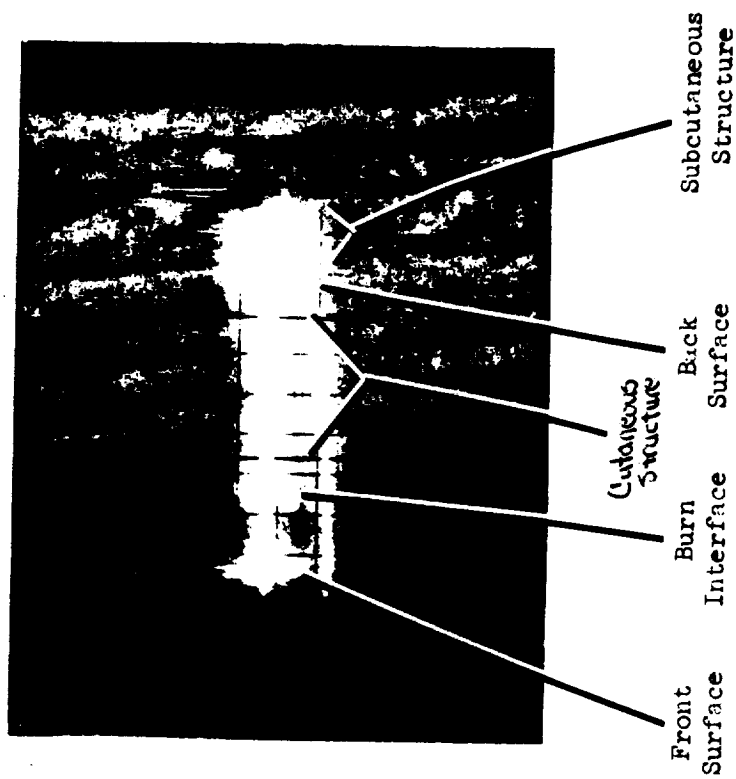


Figure 21.- 8 x 10 of Figure 20 burn location 3.



Right foot burn location 4 - 2nd degree

Skin thickness 1.05mm

Burn interface .3mm

F30B

Focused 15Mhz Xducer

Figure 22.- Right foot burn location 4.

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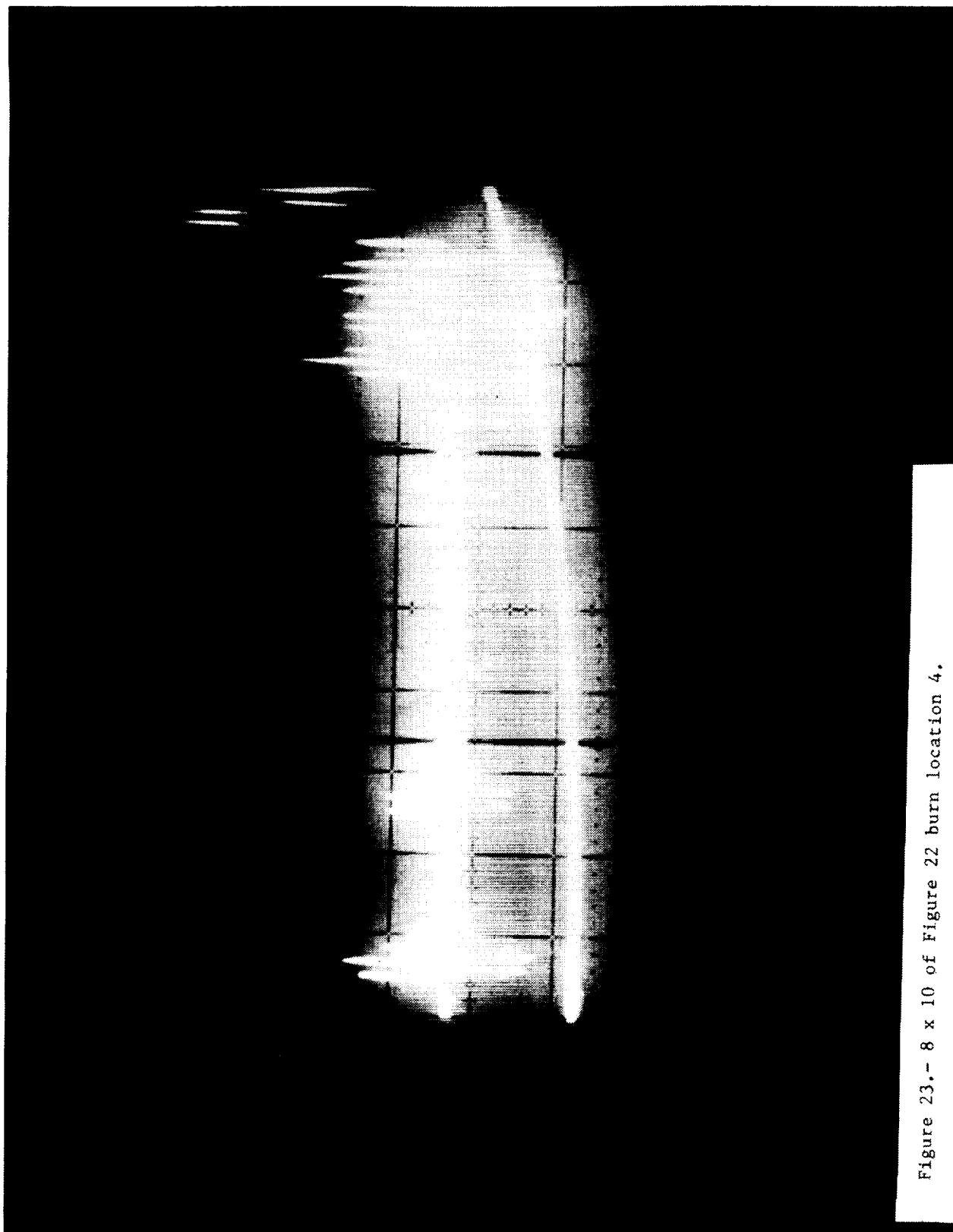
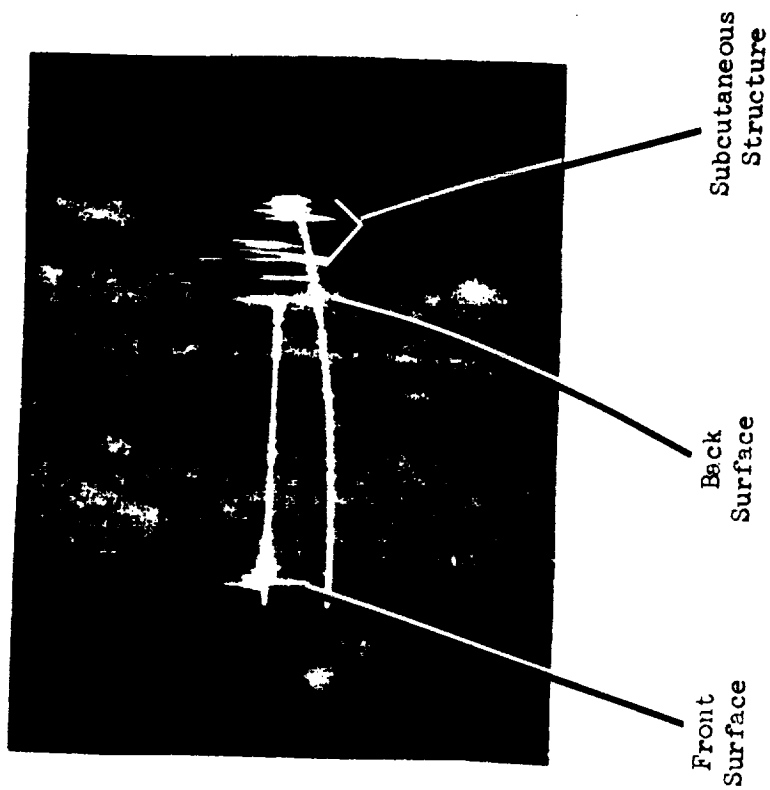


Figure 23.- 8 x 10 of Figure 22 burn location 4.



Left foot CONTROL for Right foot burn location 4

Skin thickness 1mm

F30B

Focused 15Mhz Xducer

Figure 24.- Control left foot for right foot burn location 4.

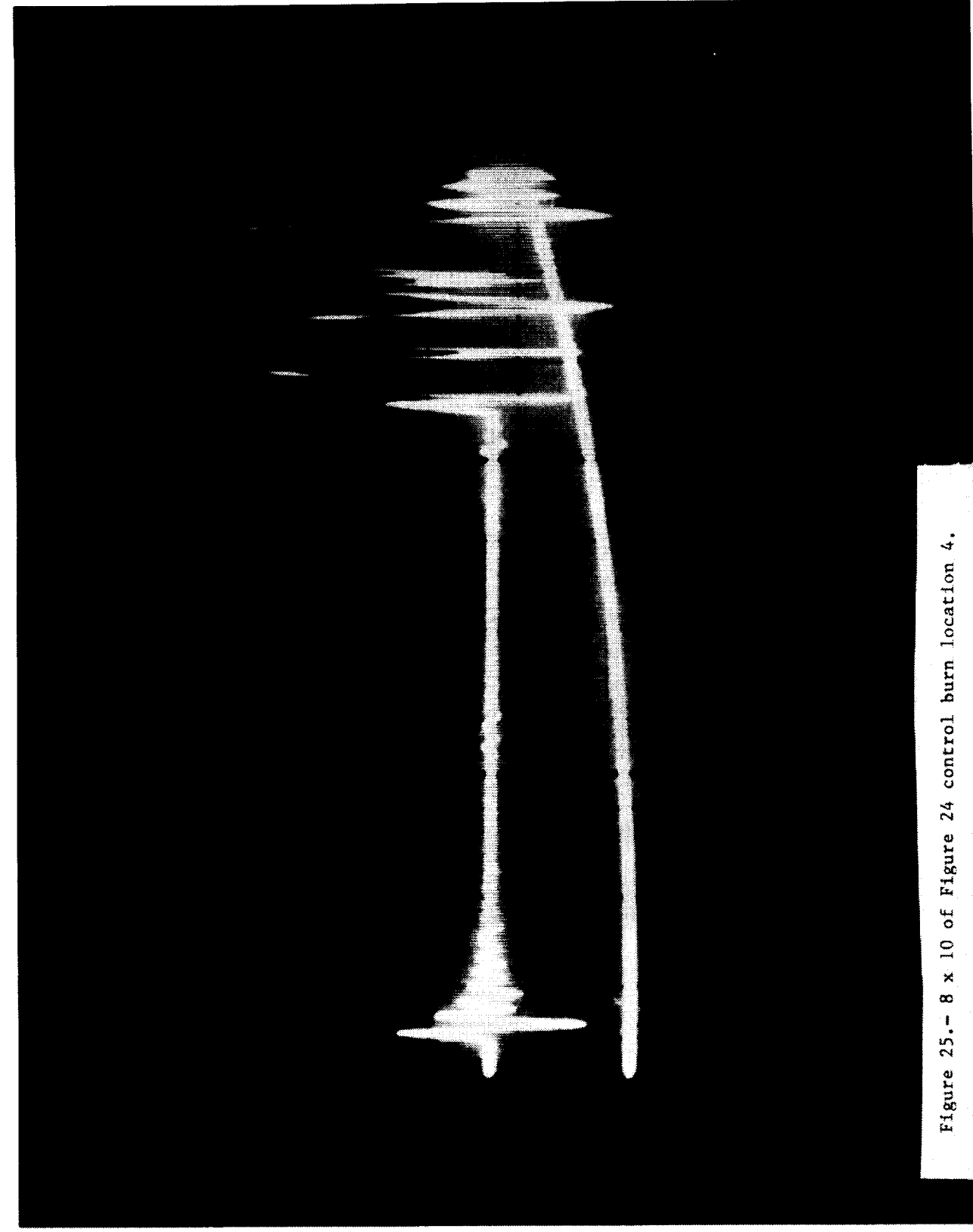
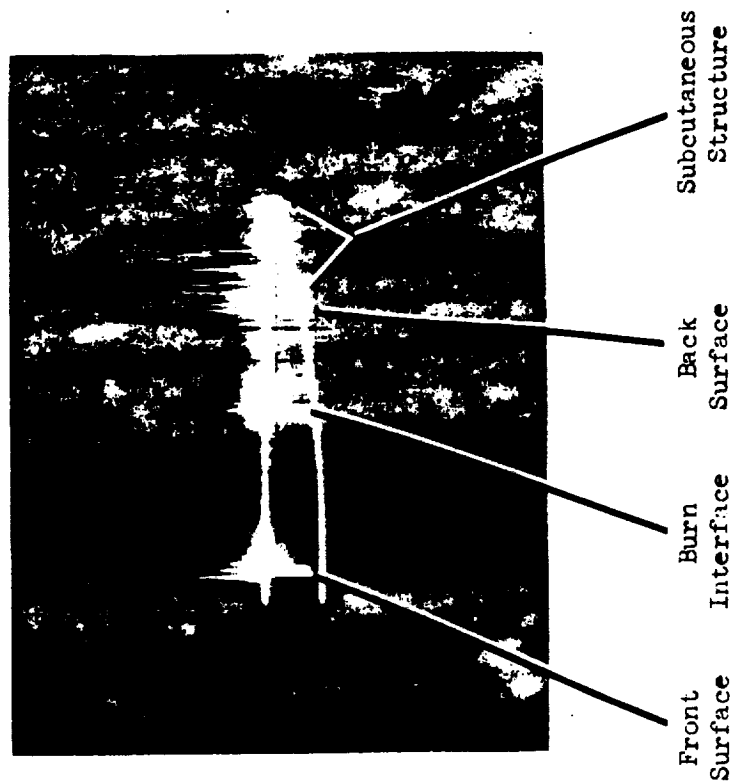


Figure 25.- 8 x 10 of Figure 24 control burn location 4.



Right foot burn location 5 - 2nd degree 2/3 thickness

Skin thickness .90mm

Burn interface .60mm

F30B

Focused 15Mhz Xducer

Figure 26.- Right foot burn location 5.

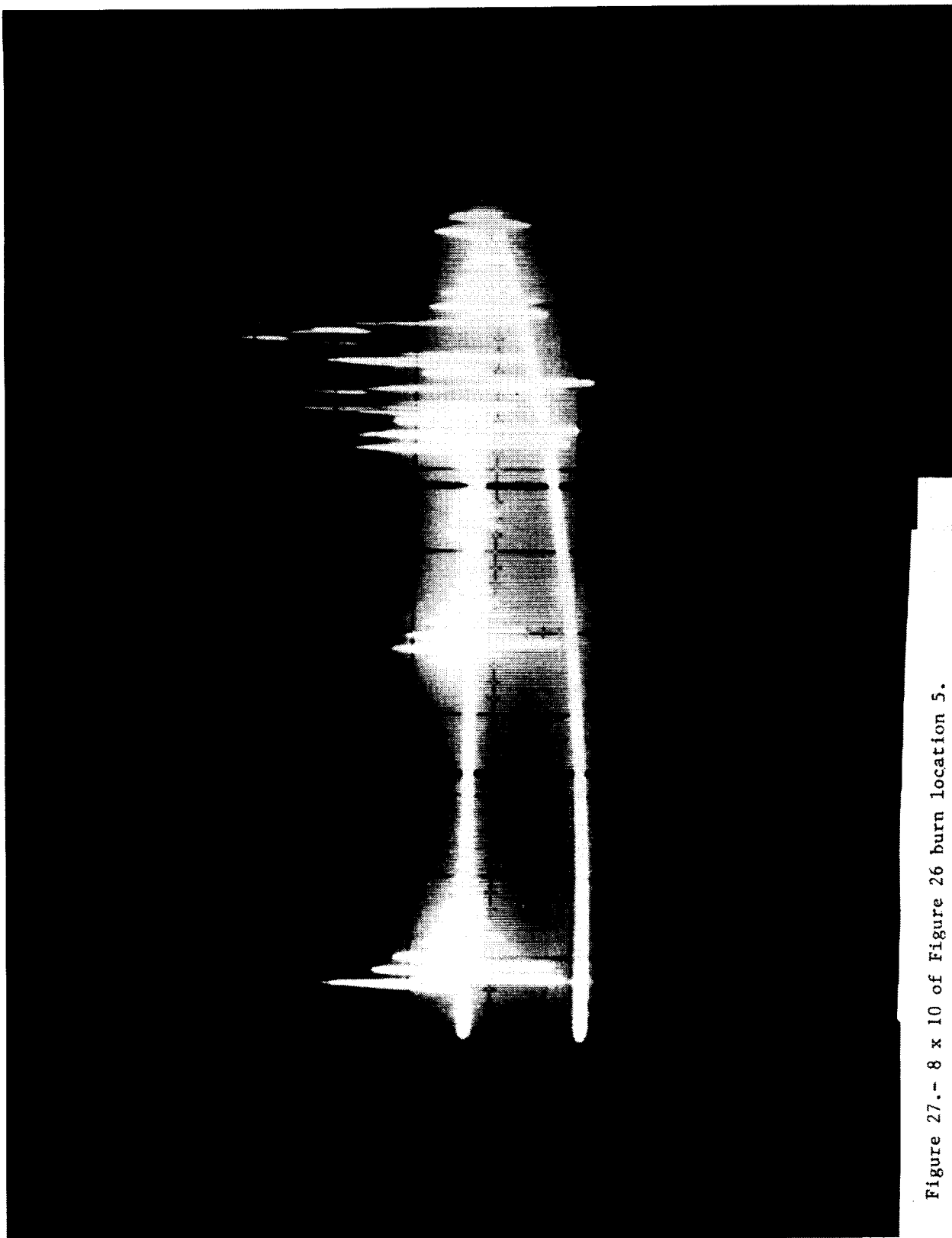
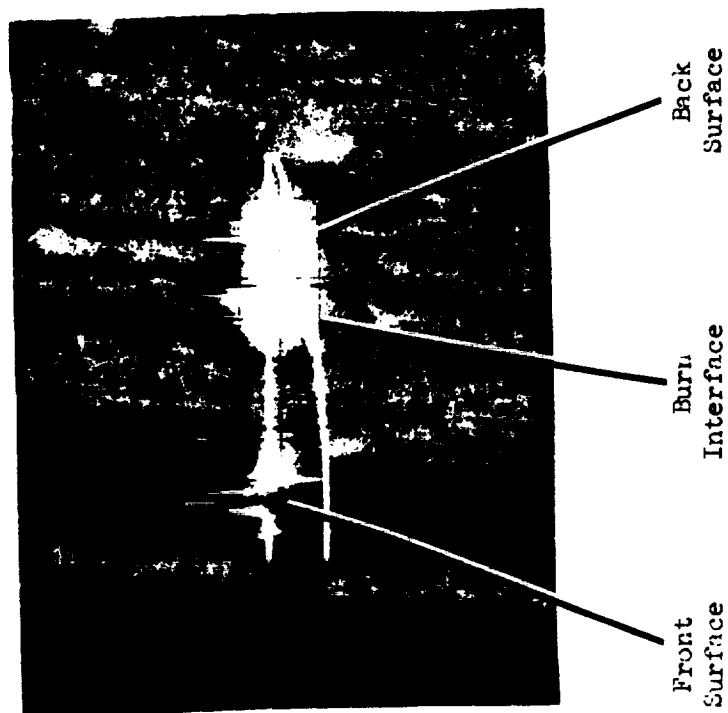


Figure 27.- 8 x 10 of Figure 26 burn location 5.

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Left foot burn location 3 - 2nd degree 2/3 thickness

Skin thickness .95mm

Burn interface .65mm

F30B

Focused 15Mhz Xducer

Figure 28.- Left foot burn location 3.

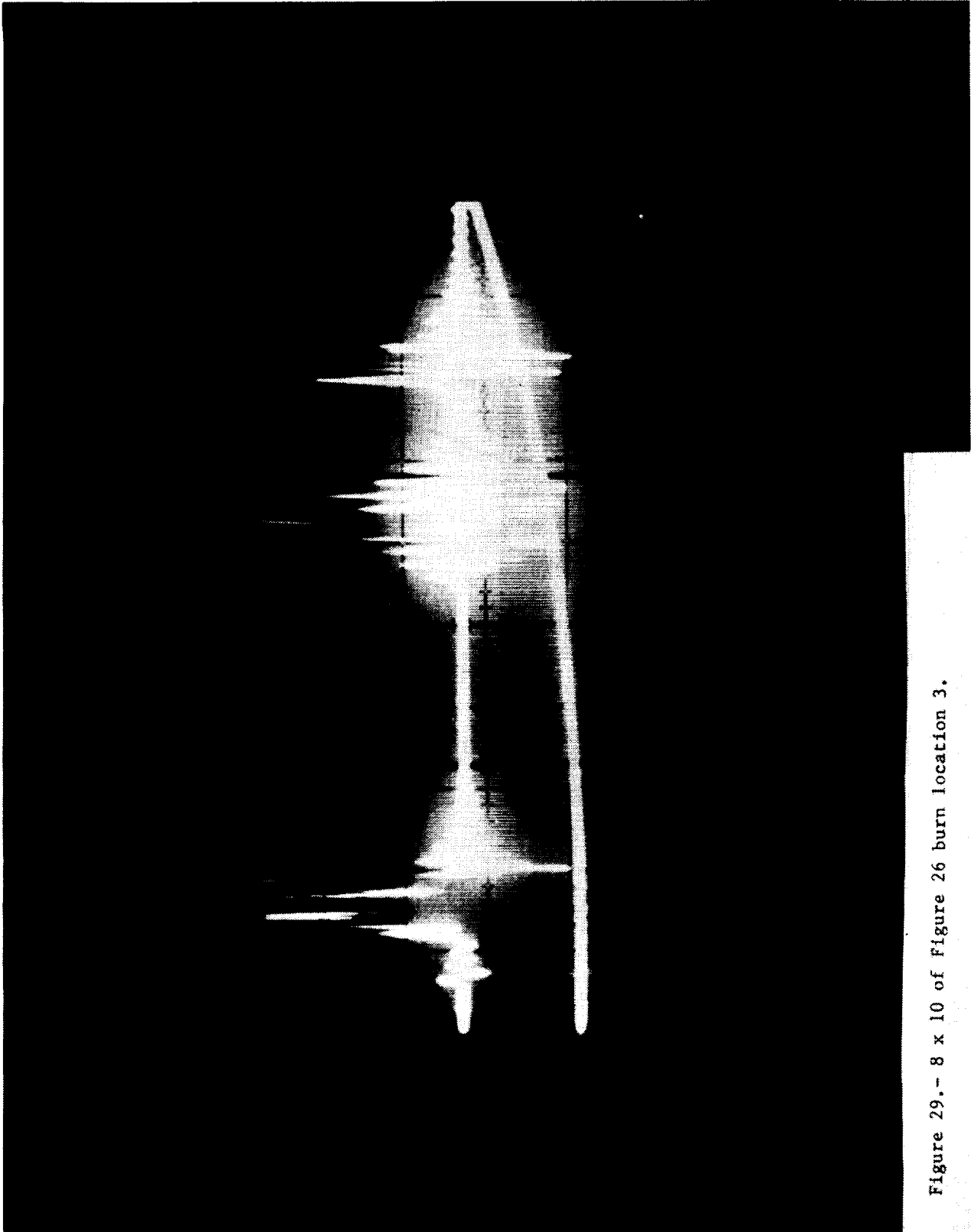
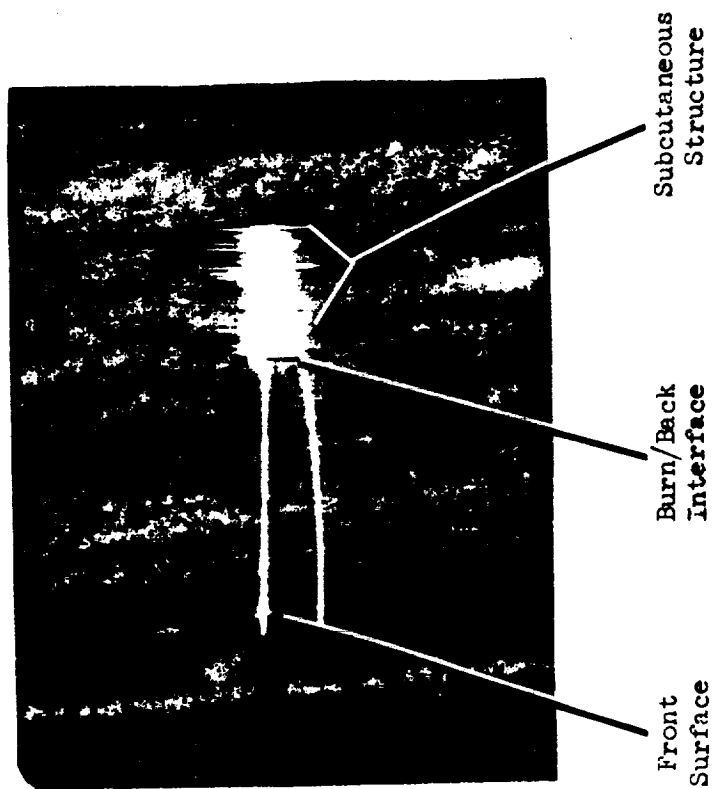


Figure 29.- 8 x 10 of Figure 26 burn location 3.



Right foot burn location 3 - 3rd degree full thickness

Skin thickness .90mm

Burn interface .90mm

F30B

Focused 15Mhz Xducer

Figure 30.- Right foot burn location 3.

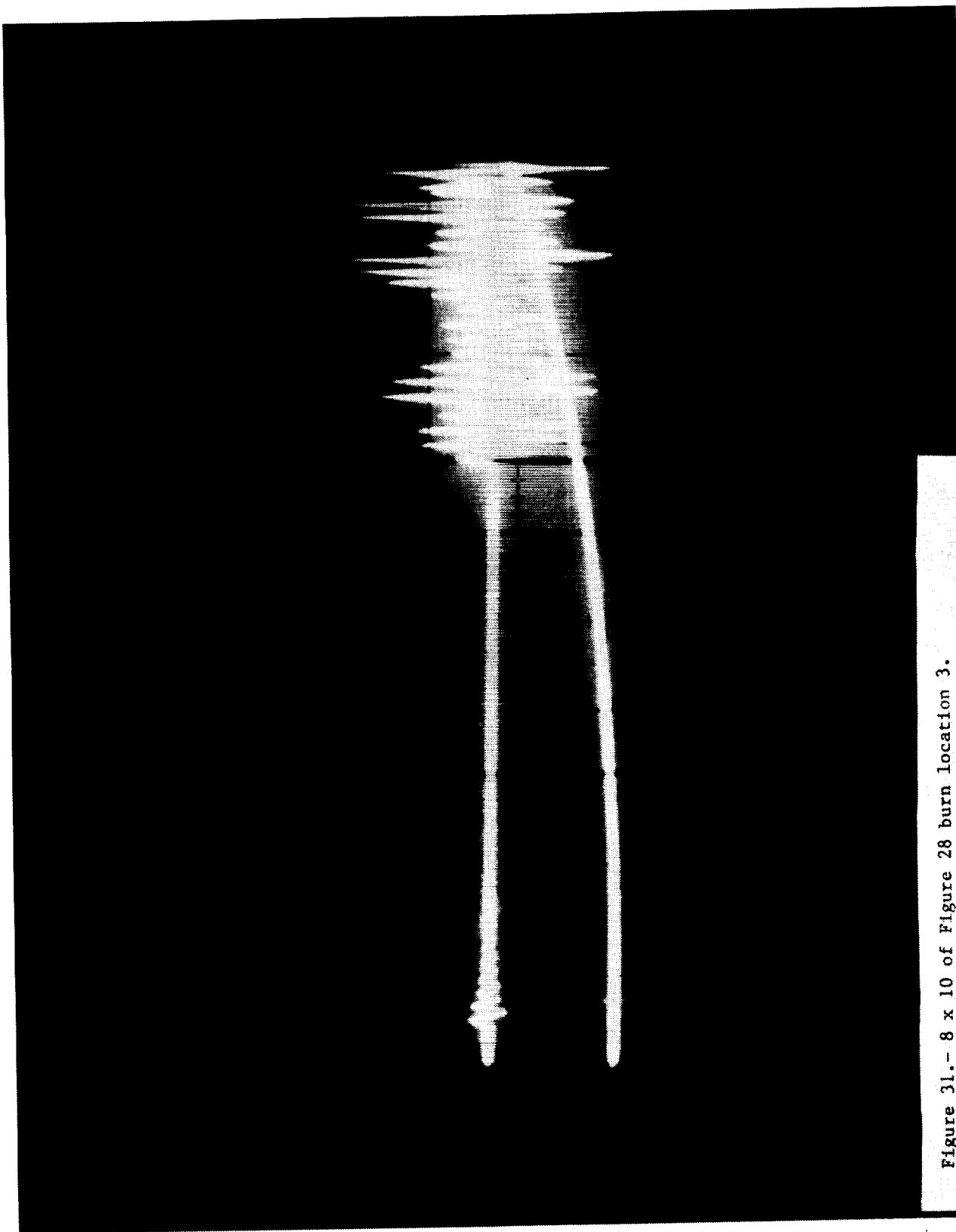


Figure 31.- 8 x 10 of Figure 28 burn location 3.



Figure 32.- 8 x 10 of patient's foot showing burn locations.

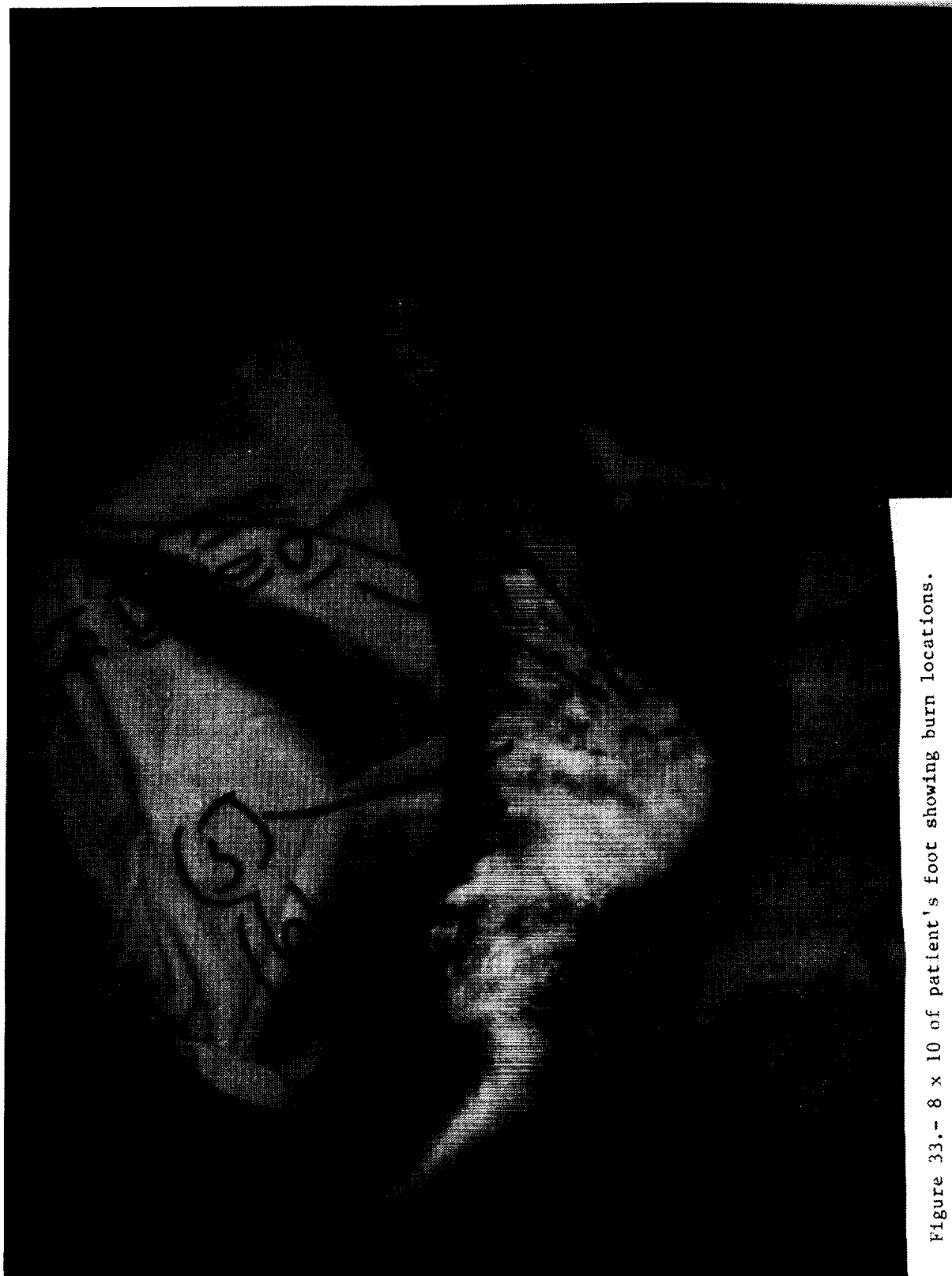
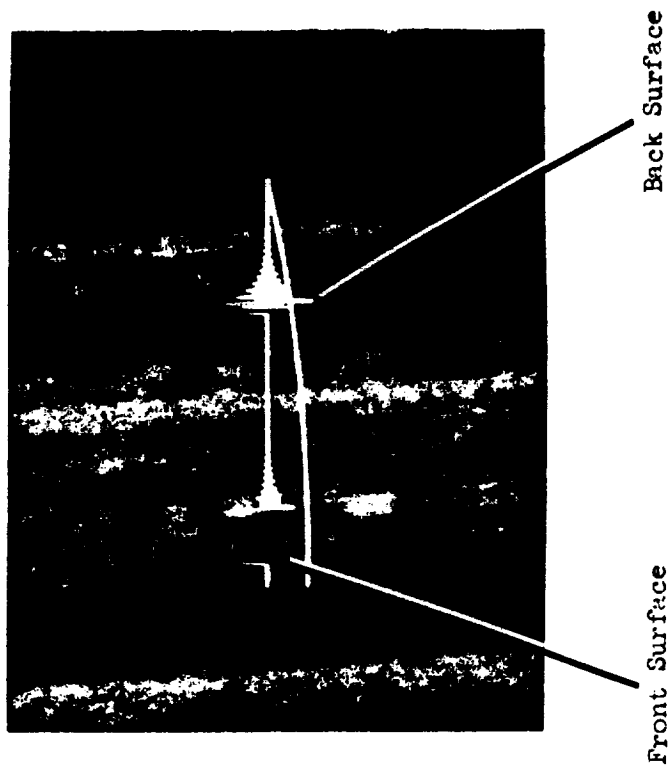


Figure 33.- 8 x 10 of patient's foot showing burn locations.



Control - Left calf
Skin thickness .85mm

F30B
Focused 15Mhz Xducer

Figure 34.- Control left calf.

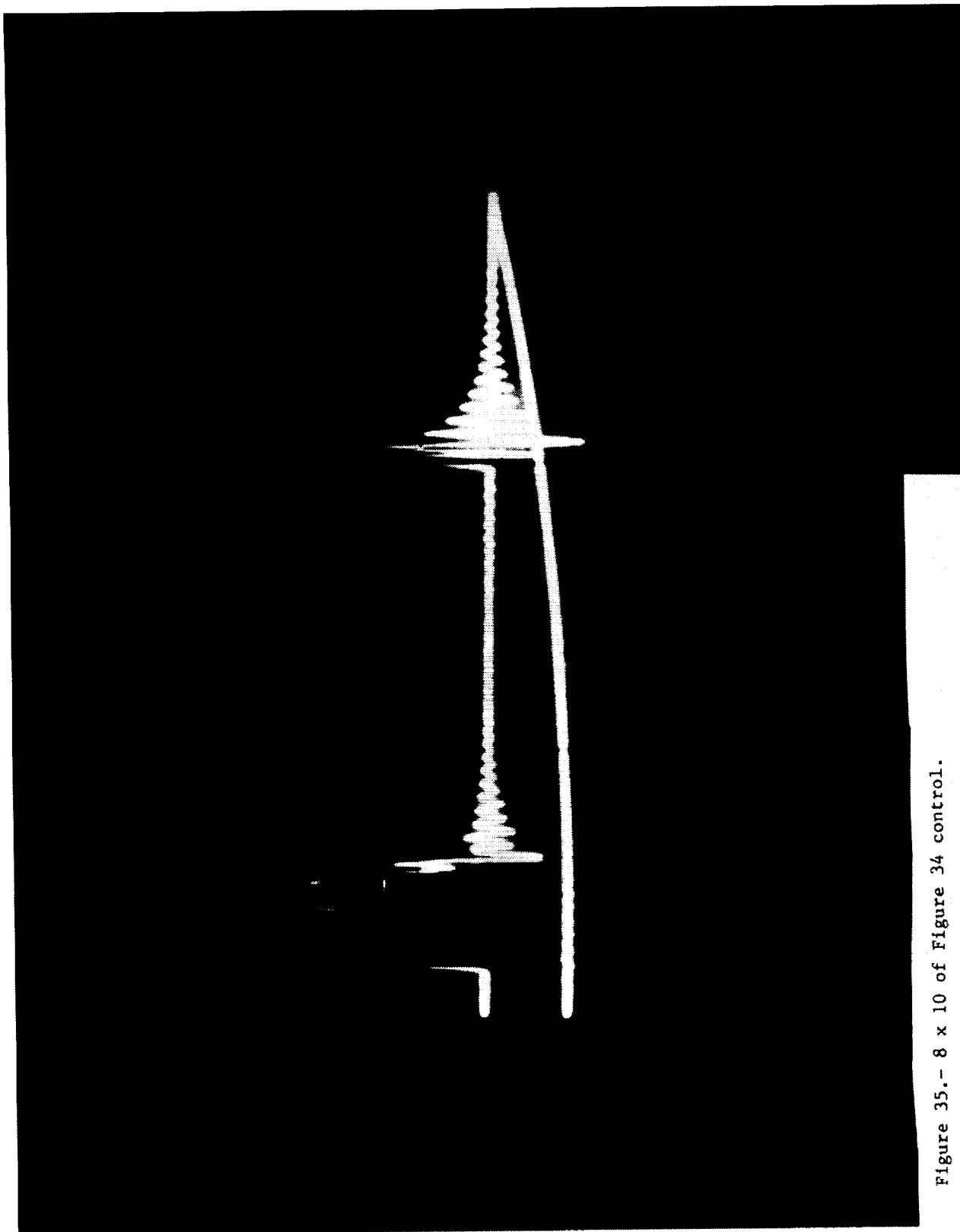
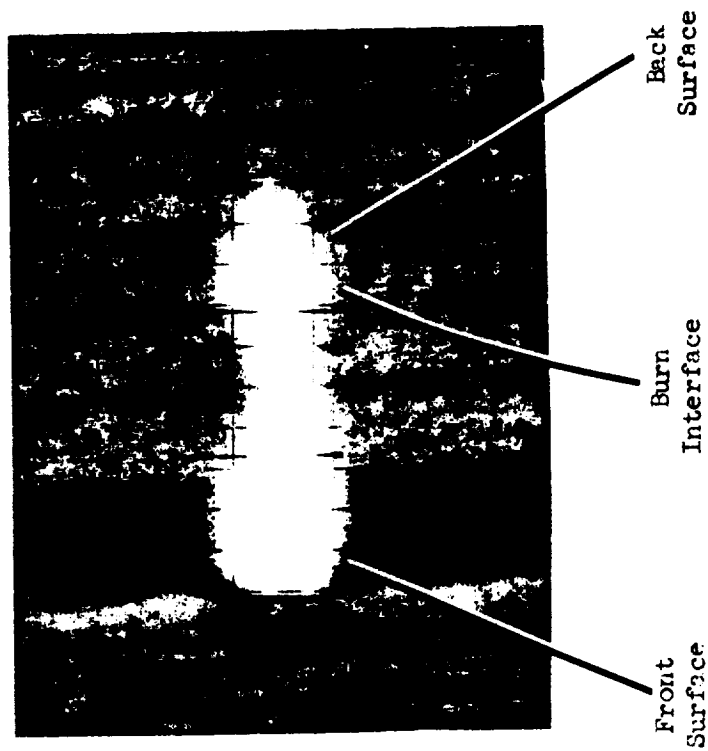


Figure 35.- 8 x 10 of Figure 34 control.



Right foot top - Burn location 2 - 2nd degree 2/3 thickness

Skin thickness 1.05mm

Burn interface .90mm

F30B

Focused 15Mhz Xducer

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Figure 36.- Right foot burn location 2.

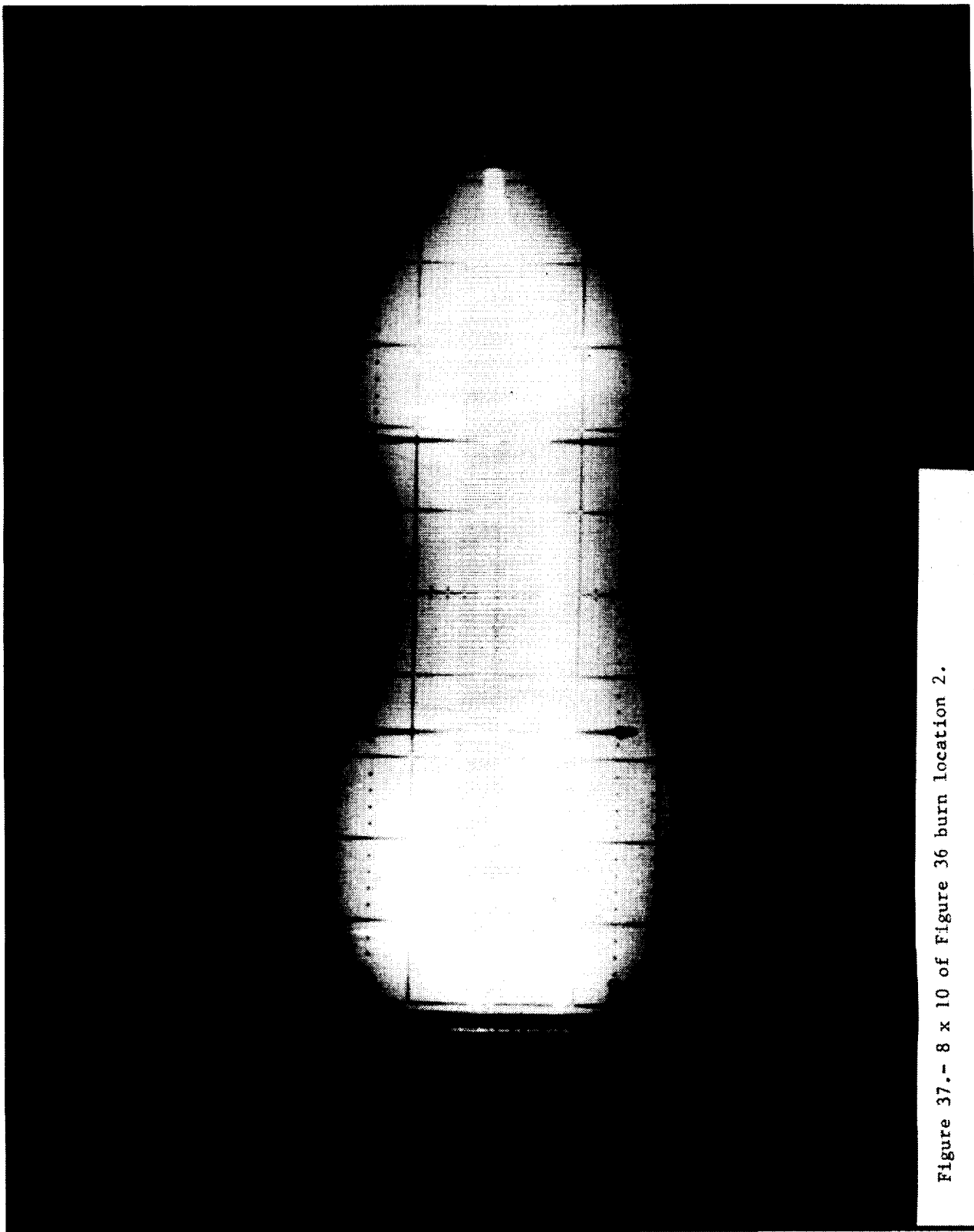
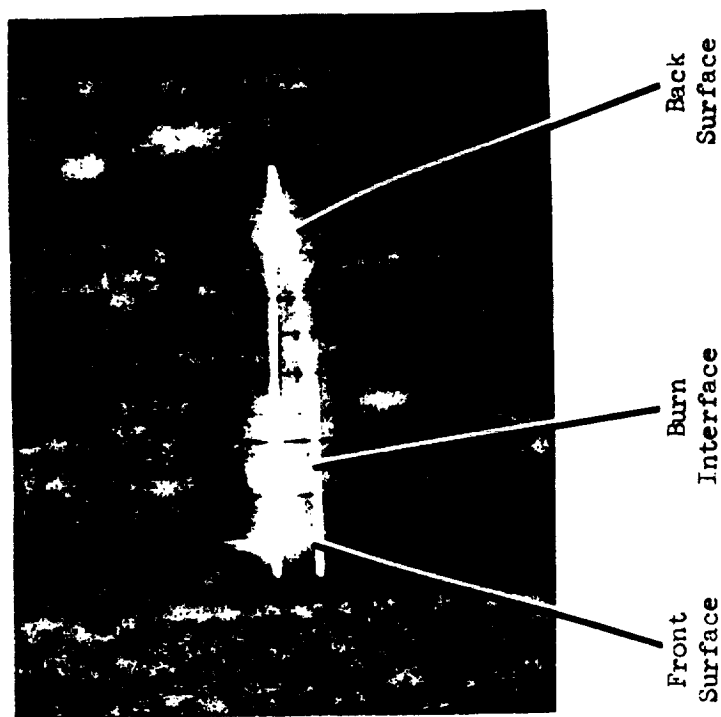


Figure 37.- 8 x 10 of Figure 36 burn location 2.



Right foot top burn location 2 - 2nd degree

Skin thickness 1.1mm

Burn interface .25mm

F30B

Focused 15Mhz Xducer

Figure 38.- Right foot burn location 2.

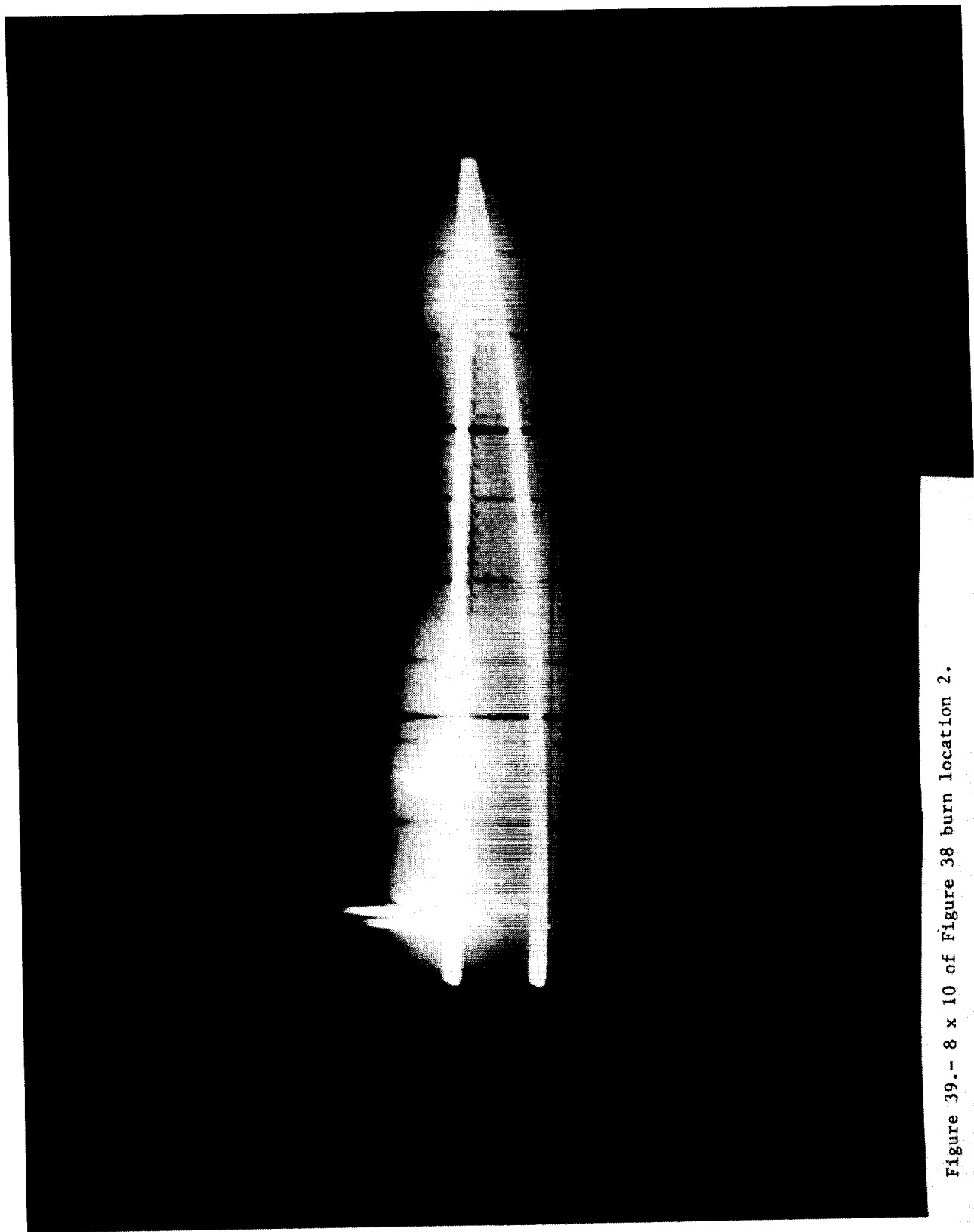
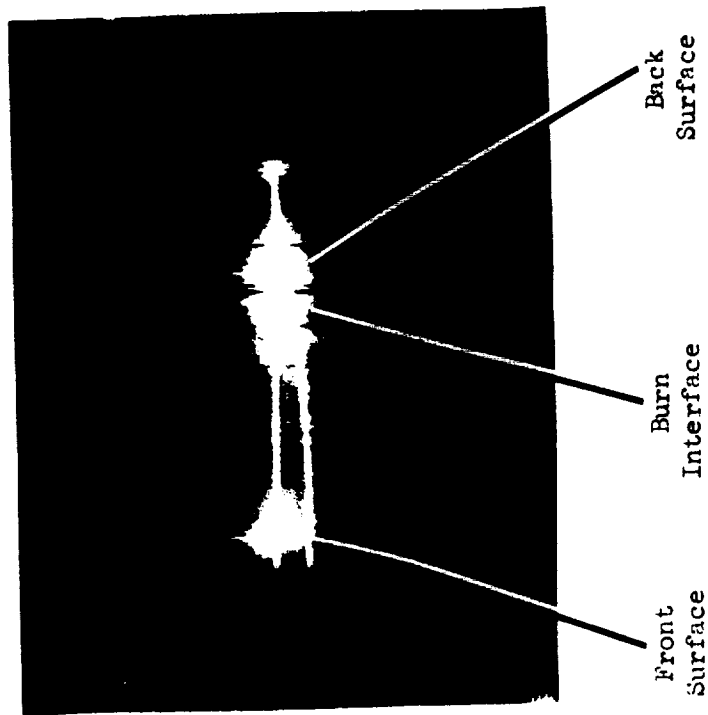


Figure 39.- 8 x 10 of Figure 38 burn location 2.



Right foot top burn location 2 - 2nd degree 2/3 thickness

Skin thickness .95mm

Burn thickness .85mm

F30B

Focused 15Mhz Xducer

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Figure 40.- Right foot burn location 2.

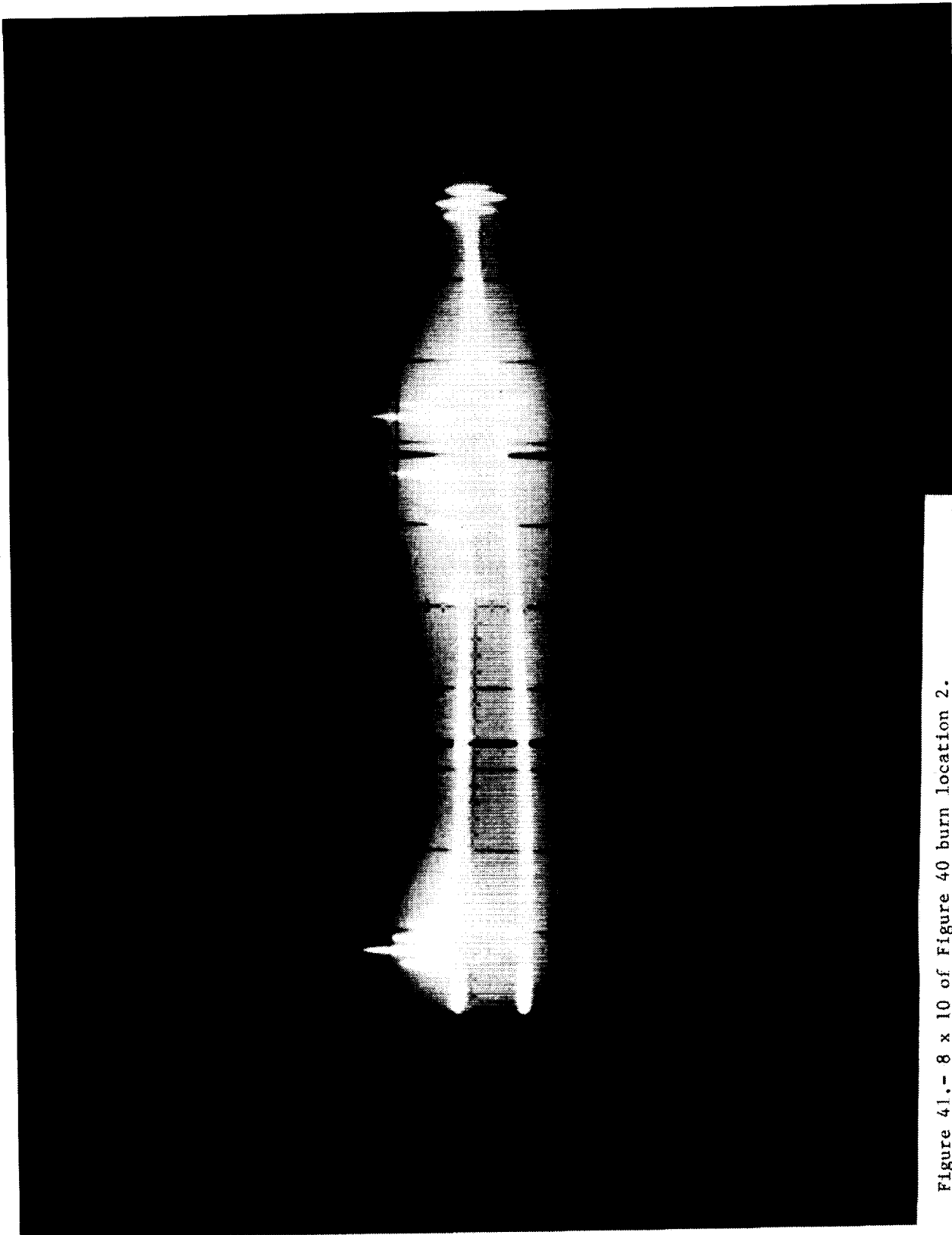
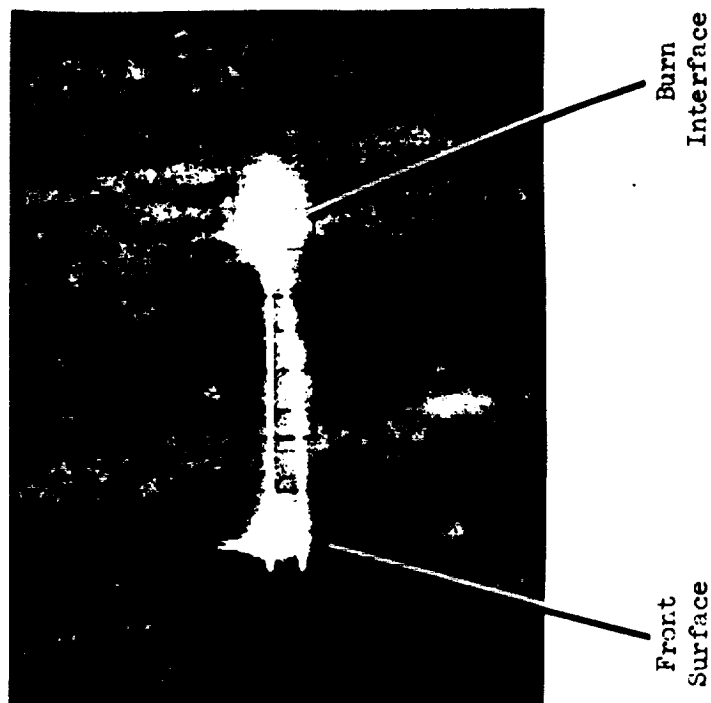


Figure 41.- 8 x 10 of Figure 40 burn location 2.



right foot burn location 5 - full thickness burn

Burn interface 1.1mm

F30B

Focused 15Mhz Xducer

Figure 42.- Right foot burn location 5.

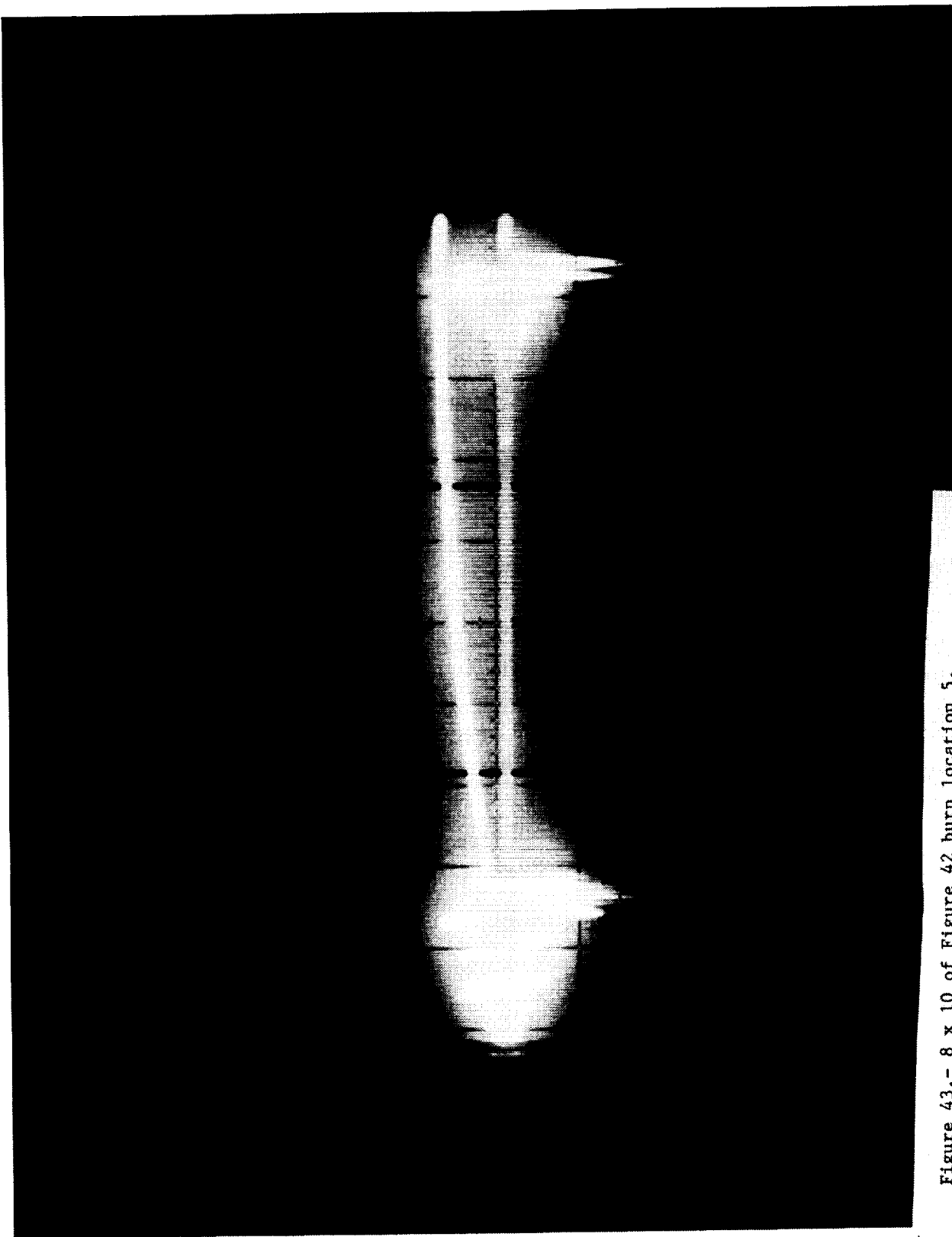
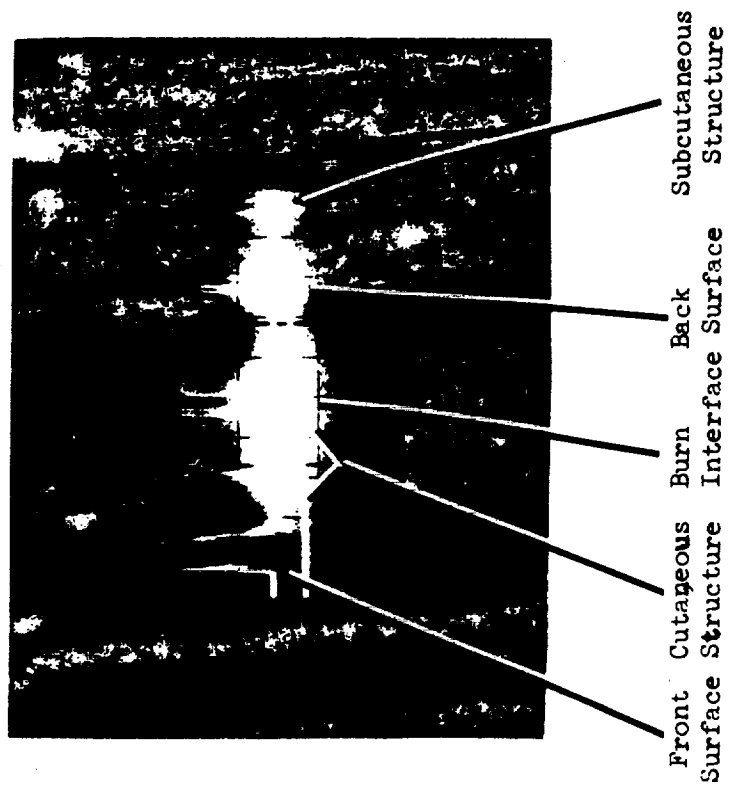


Figure 43.- 8 x 10 of Figure 42 burn location 5.



Right foot burn location 5 - 2nd degree 1/2 thickness

Skin thickness 1.0mm

Burn interface .55mm

F30B

Focused 15Mhz Xducer

Figure 44.- Right foot burn location 5.

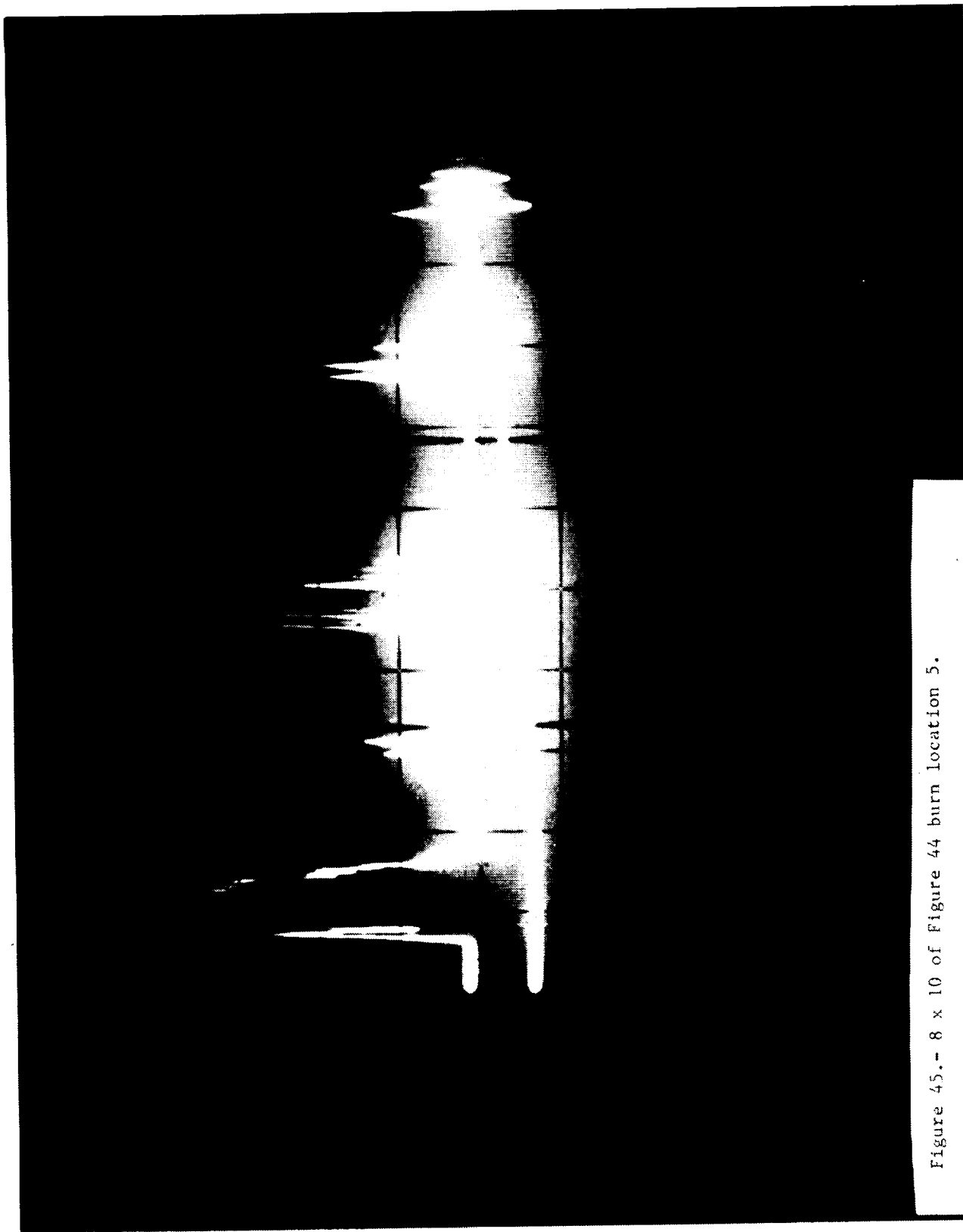
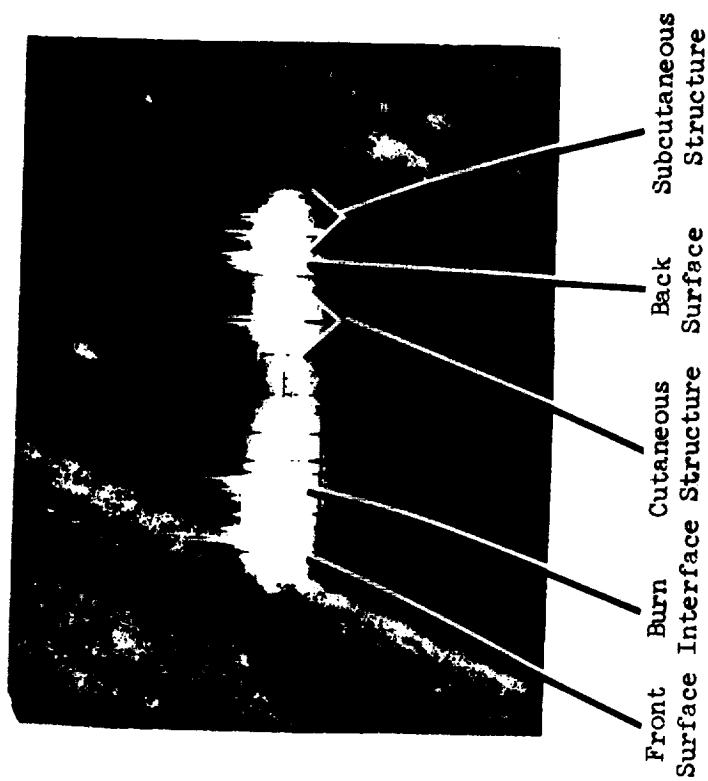


Figure 45.- 8 x 10 of Figure 44 burn location 5.



Right foot burn location 5 - 2nd degree

Skin thickness 1.0mm

Burn interface .20mm

F30B

Focused 15Mhz Xducer

Figure 46.- Right foot burn location 5.

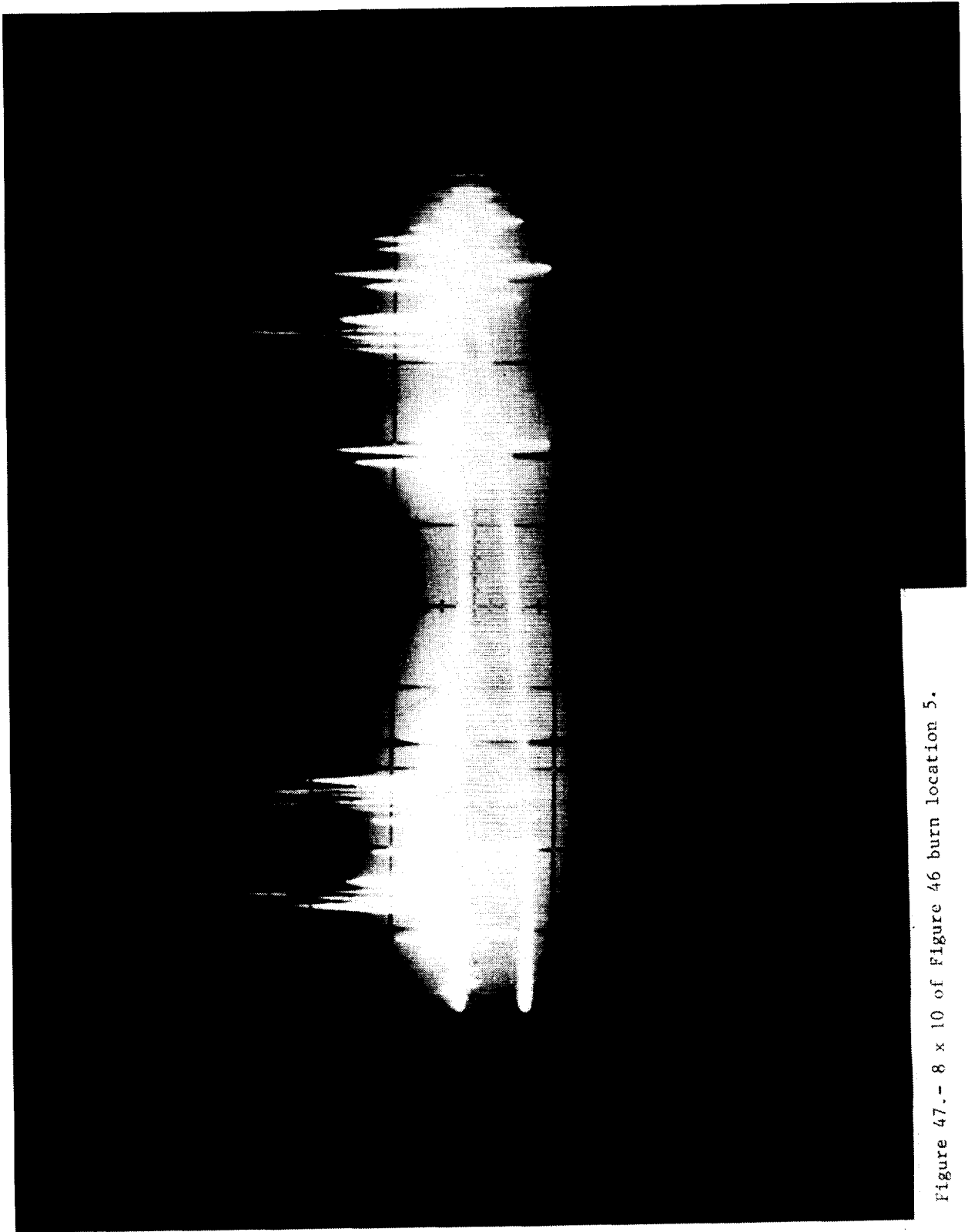
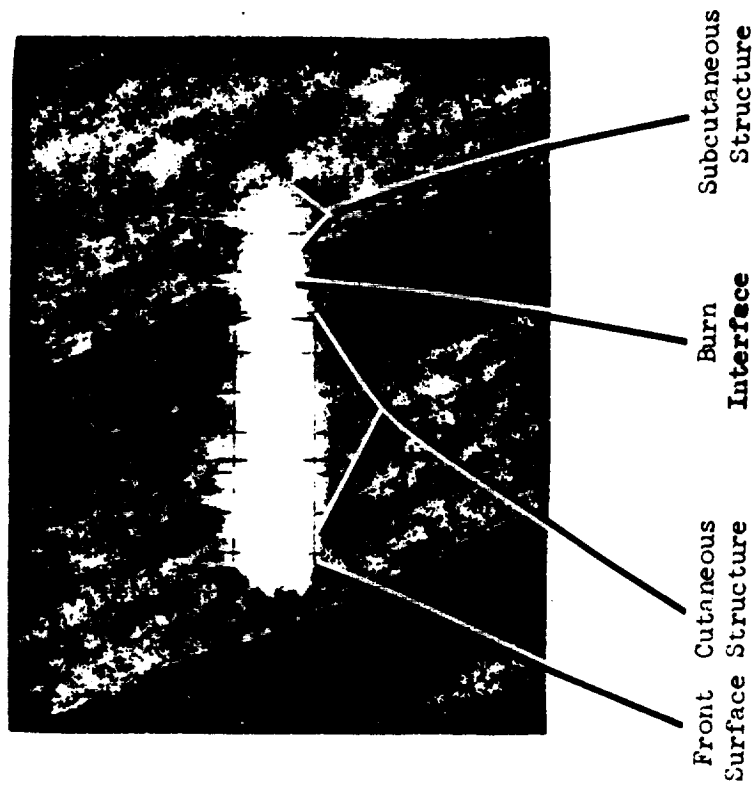


Figure 47.- 8 x 10 of Figure 46 burn location 5.



Right foot burn location 8 - full thickness burn

Burn interface 1.0mm

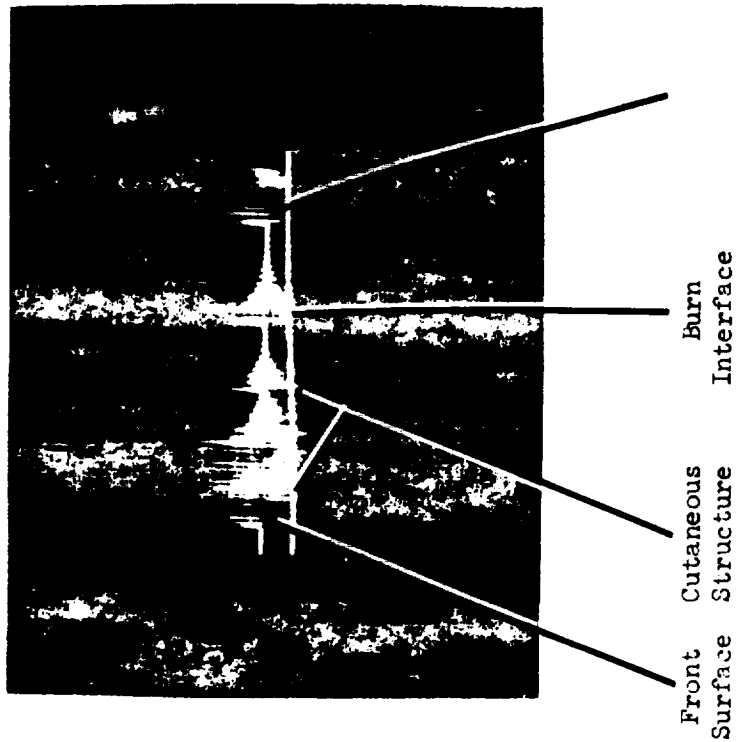
F30B

Focused 15Mhz Xducer

Figure 48.- Right foot burn location 8.



Figure 49.- 8 x 10 of Figure 48 burn location 8.



Right foot burn location 8 - 2nd degree 2/3 thickness

Skin thickness 1.15mm

Burn interface .75mm

F30B

Focused 15Mhz Xducer

Figure 50.- Right foot burn location 8.

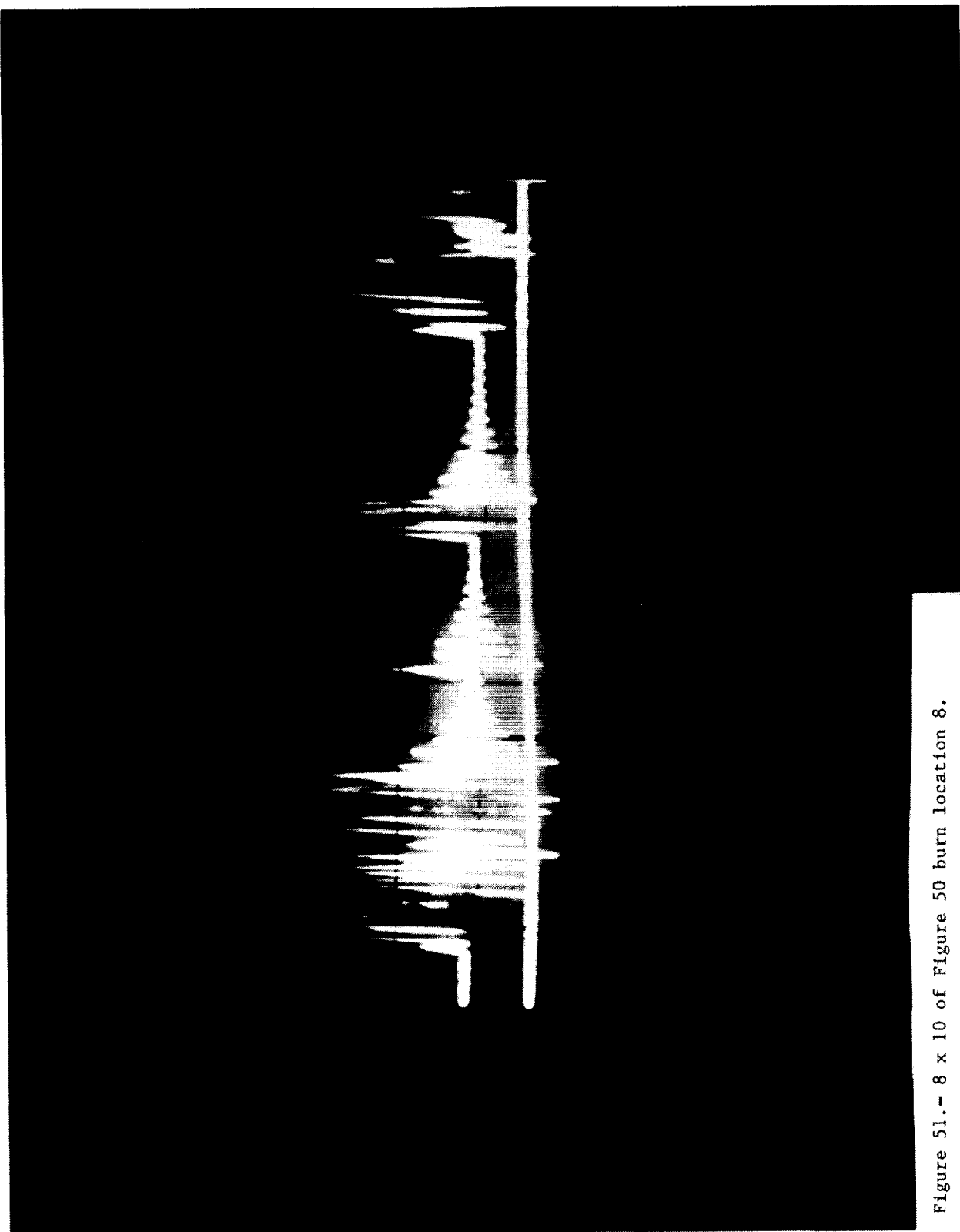
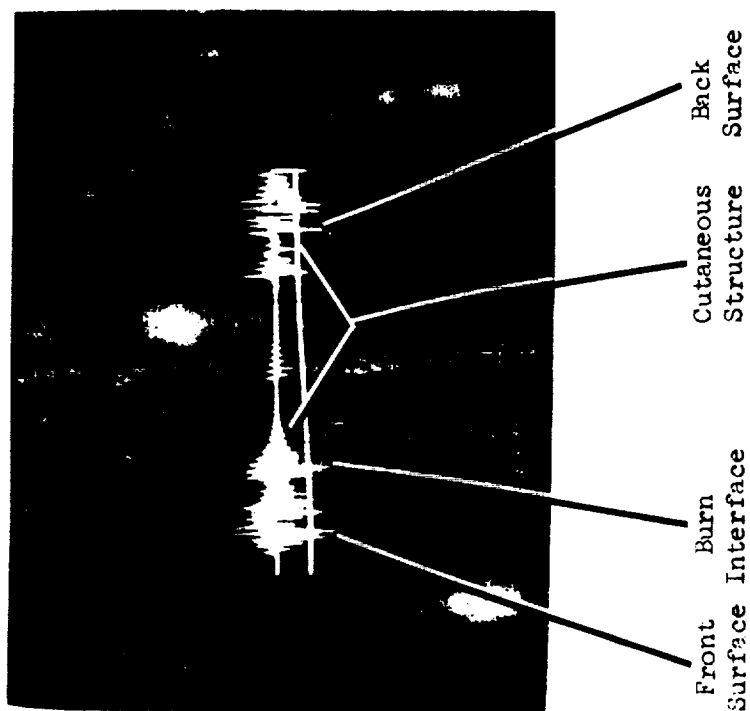


Figure 51.- 8 x 10 of Figure 50 burn location 8.



Right foot burn location 8 - 2nd degree

Skin thickness 1.1mm

Burn interface .25mm

F30B

Unfocused 20Mhz Xducer

Figure 52.- Right foot burn location 8.

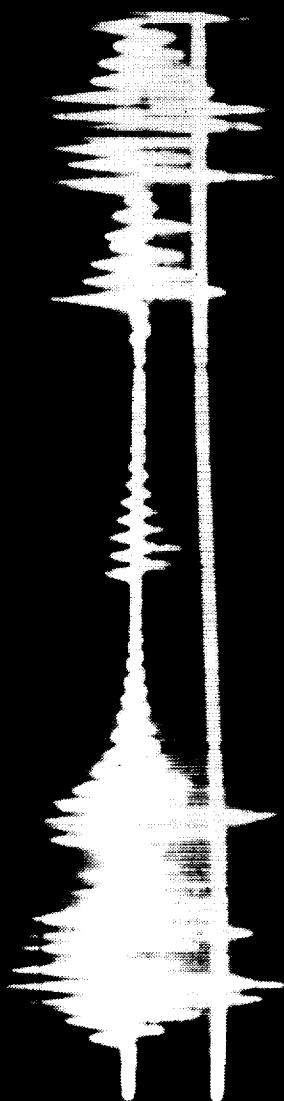
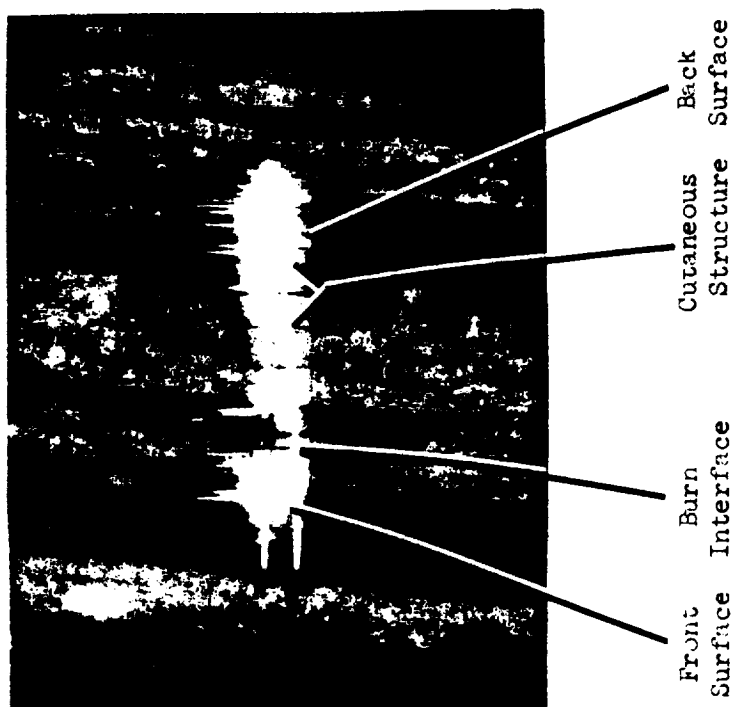


Figure 53.- 8 x 10 of Figure 52 burn location 8.



Right foot burn location 9 - 2nd degree

Skin thickness 1.0mm

Burn interface .20mm

F30B

Unfocused 20Mhz Xducer

Figure 54.- Right foot burn location 9.

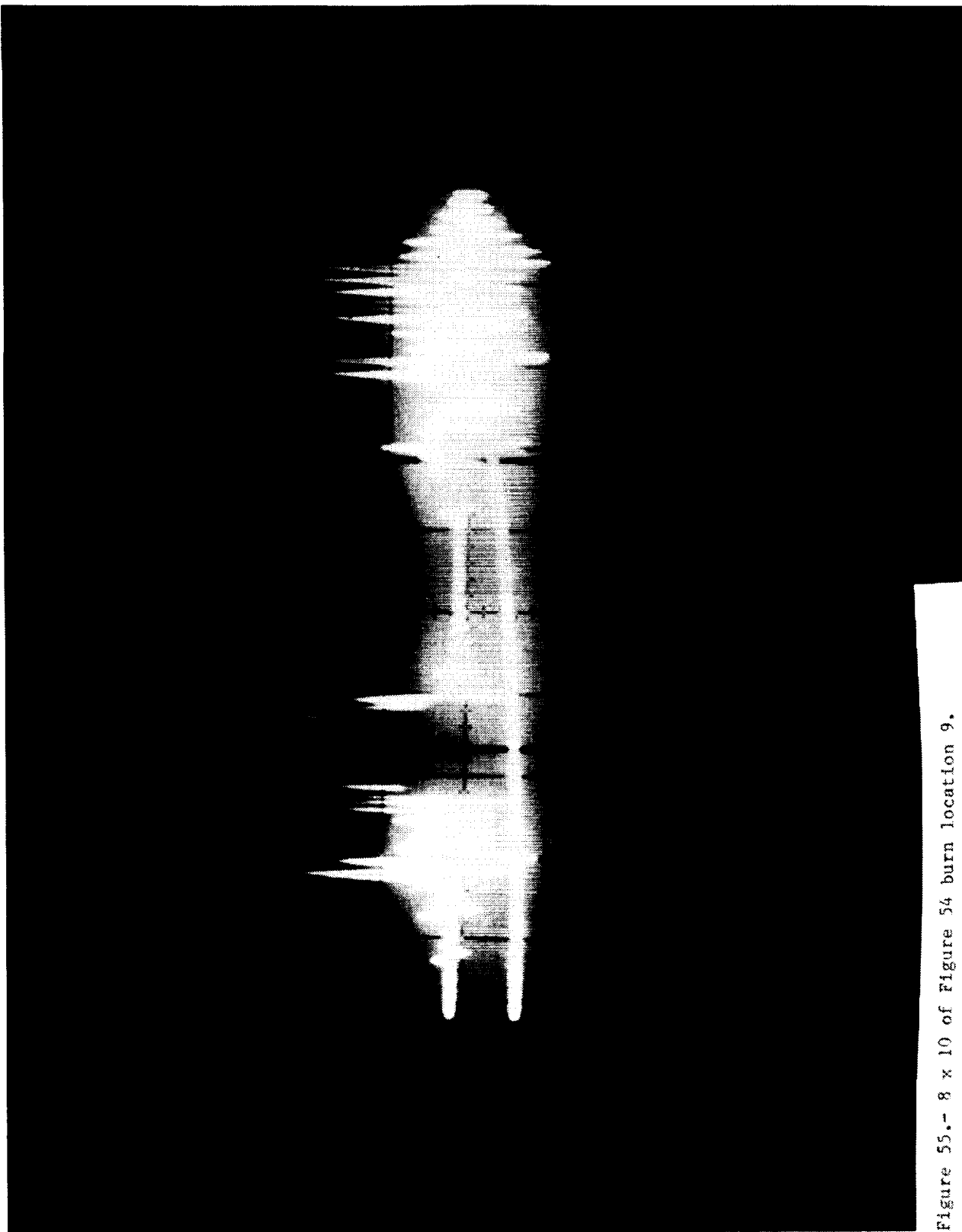
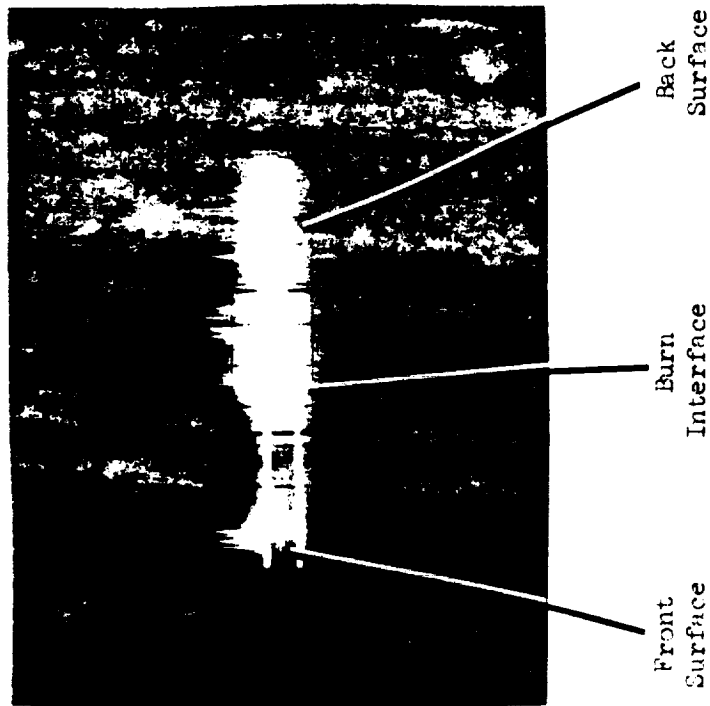


Figure 55.- 8 x 10 of Figure 54 burn location 9.



Right foot burn location 10 - 2nd degree 1/2 thickness

Skin thickness 1.1mm

Burn interface .60mm

F30B

Unfocused 20Mhz Xducer

Figure 56.- Right foot burn location 10.

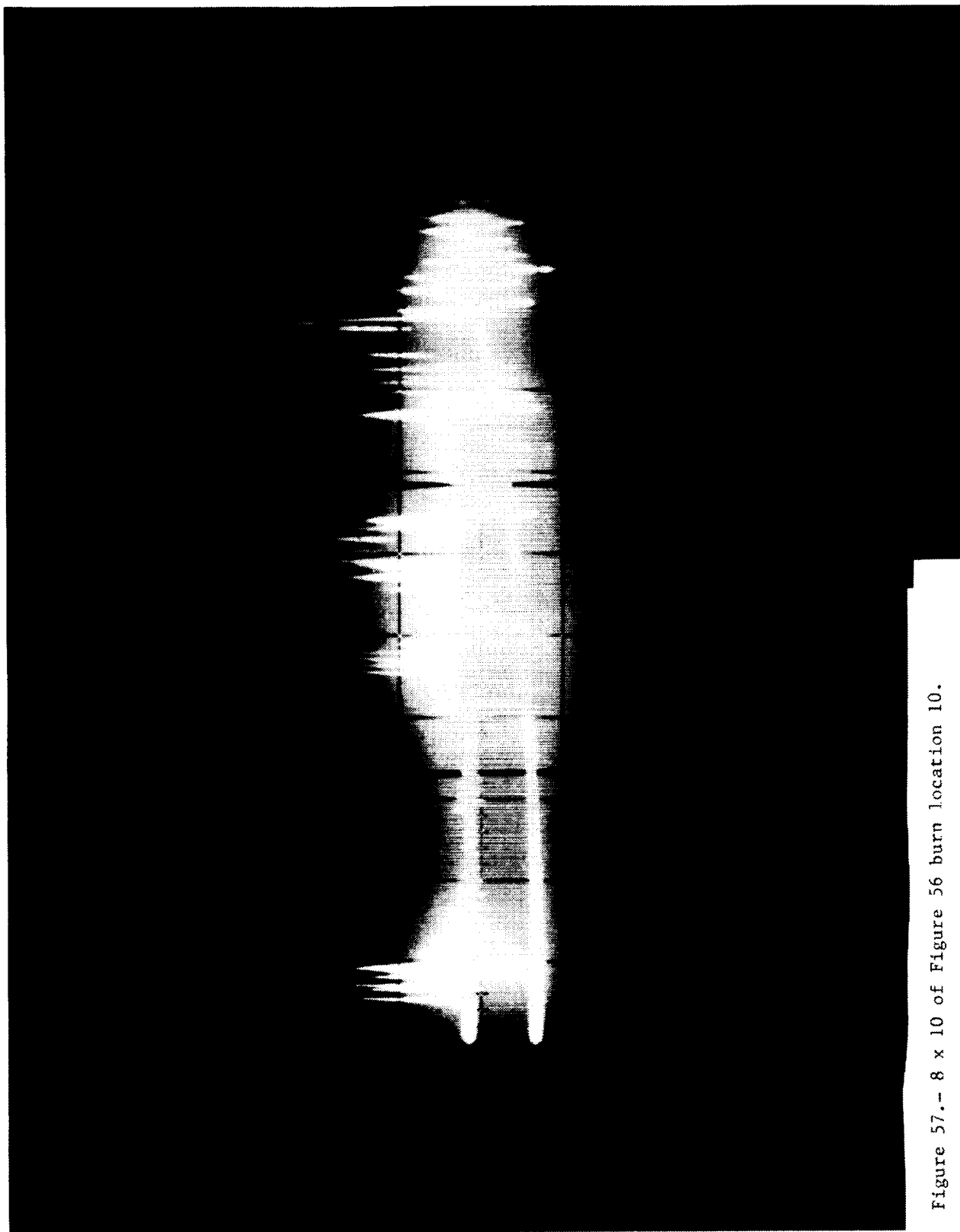
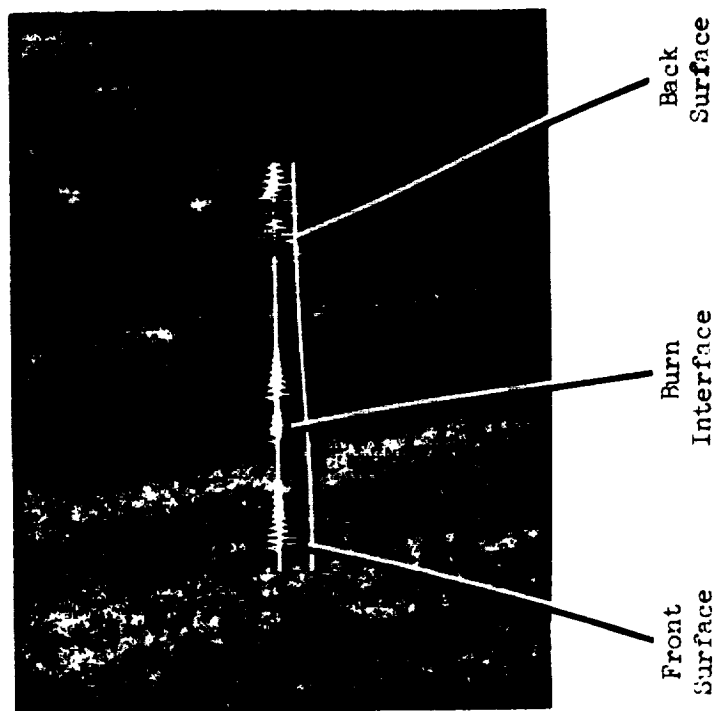


Figure 57.-- 8 x 10 of Figure 56 burn location 10.



Right foot burn location 10 - 2nd degree

Skin thickness 1.0mm

Burn interface .40mm

F30E

Unfocused 20Mhz Xducer

Figure 58.- Right foot burn location 10.

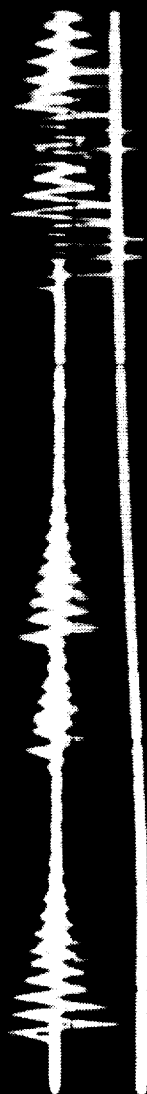
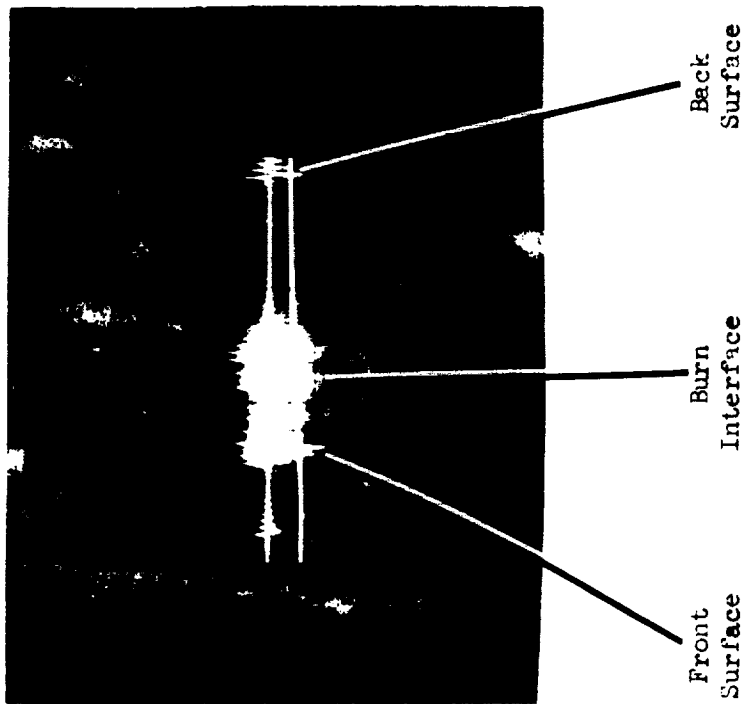


Figure 59.- 8 x 10 of Figure 58 burn location 10.



Right foot burn location 10 - 2nd degree

Skin thickness 1.0mm

Burn interface .30mm

F30B

Unfocused 20Mhz Xducer

Figure 60.- Right foot burn location 10.

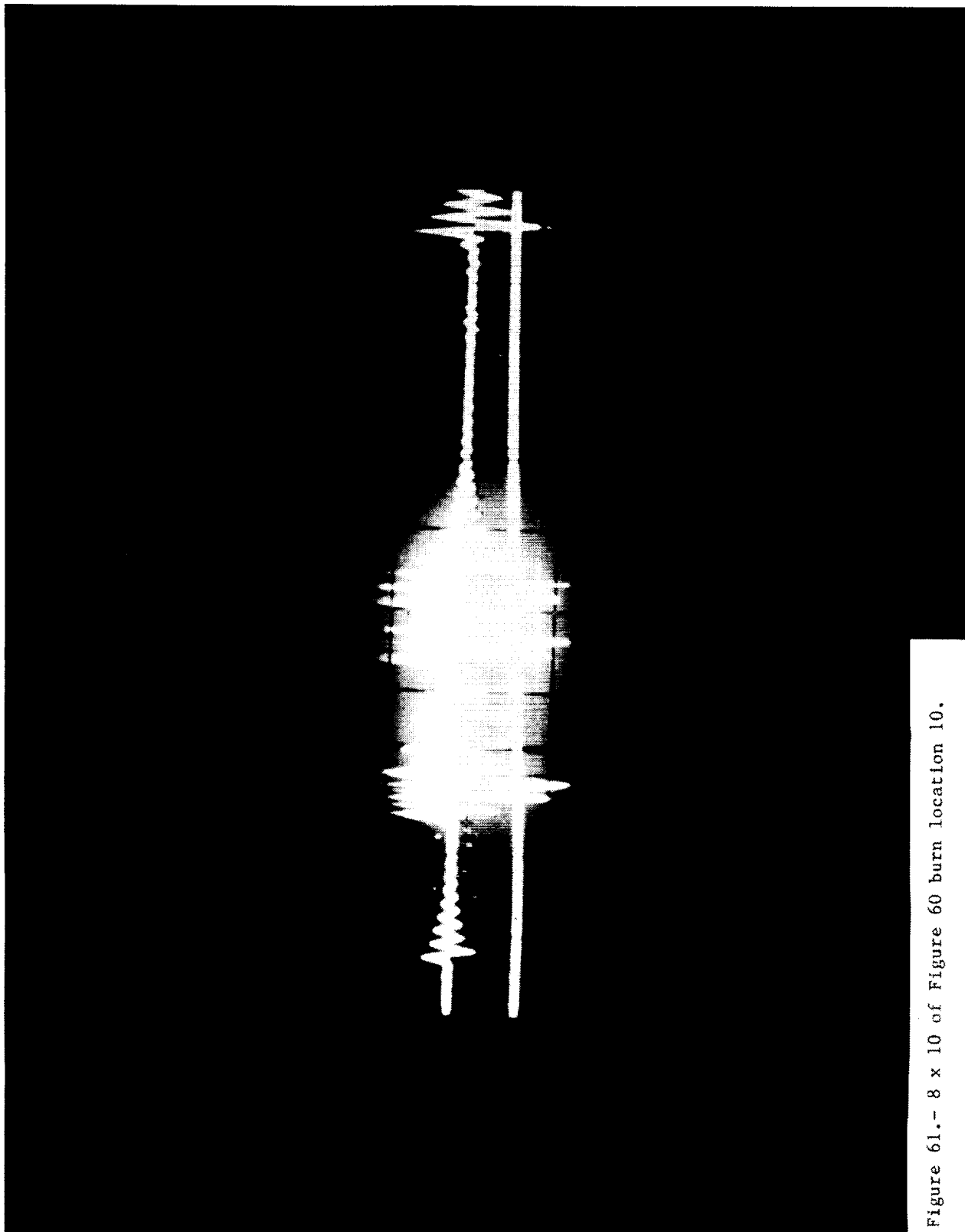
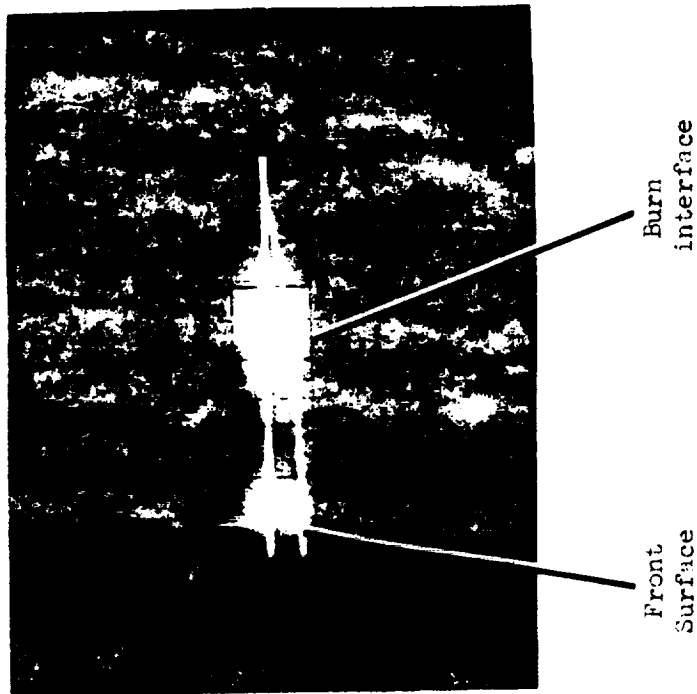


Figure 61.- 8 x 10 of Figure 60 burn location 10.



Right foot burn location 10-- 2nd degree 1/2 thickness

Burn interface .65mm

F30B

Unfocused 20Mhz Xducer

Figure 62.- Right foot burn location 10.

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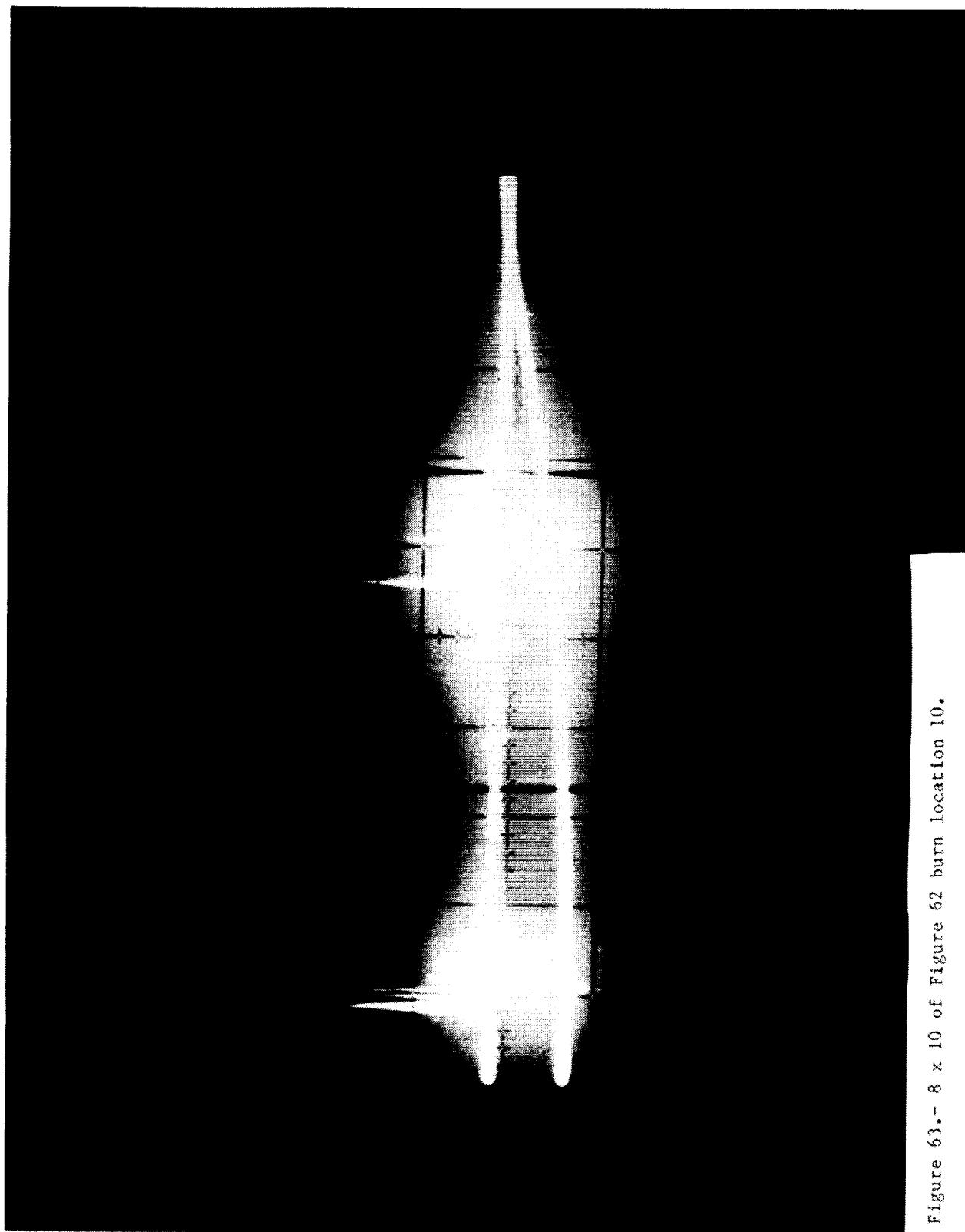
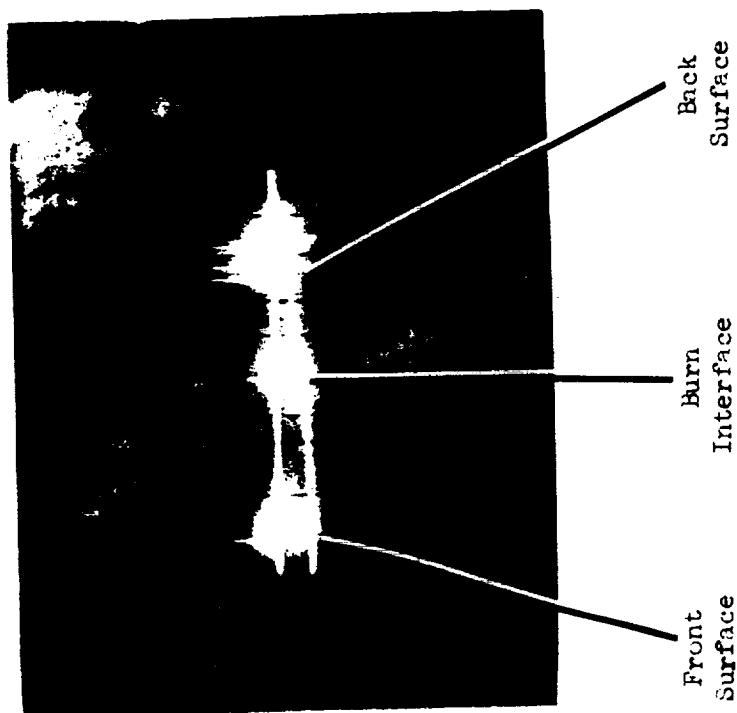


Figure 63.- 8 x 10 of Figure 62 burn location 10.



Right foot burn location 10 - 2nd degree 1/2 thickness

Skin thickness 1.05mm

Burn interface .55mm

F30B

Unfocused 20Mhz Xducer

Figure 64.- Right foot burn location 10.

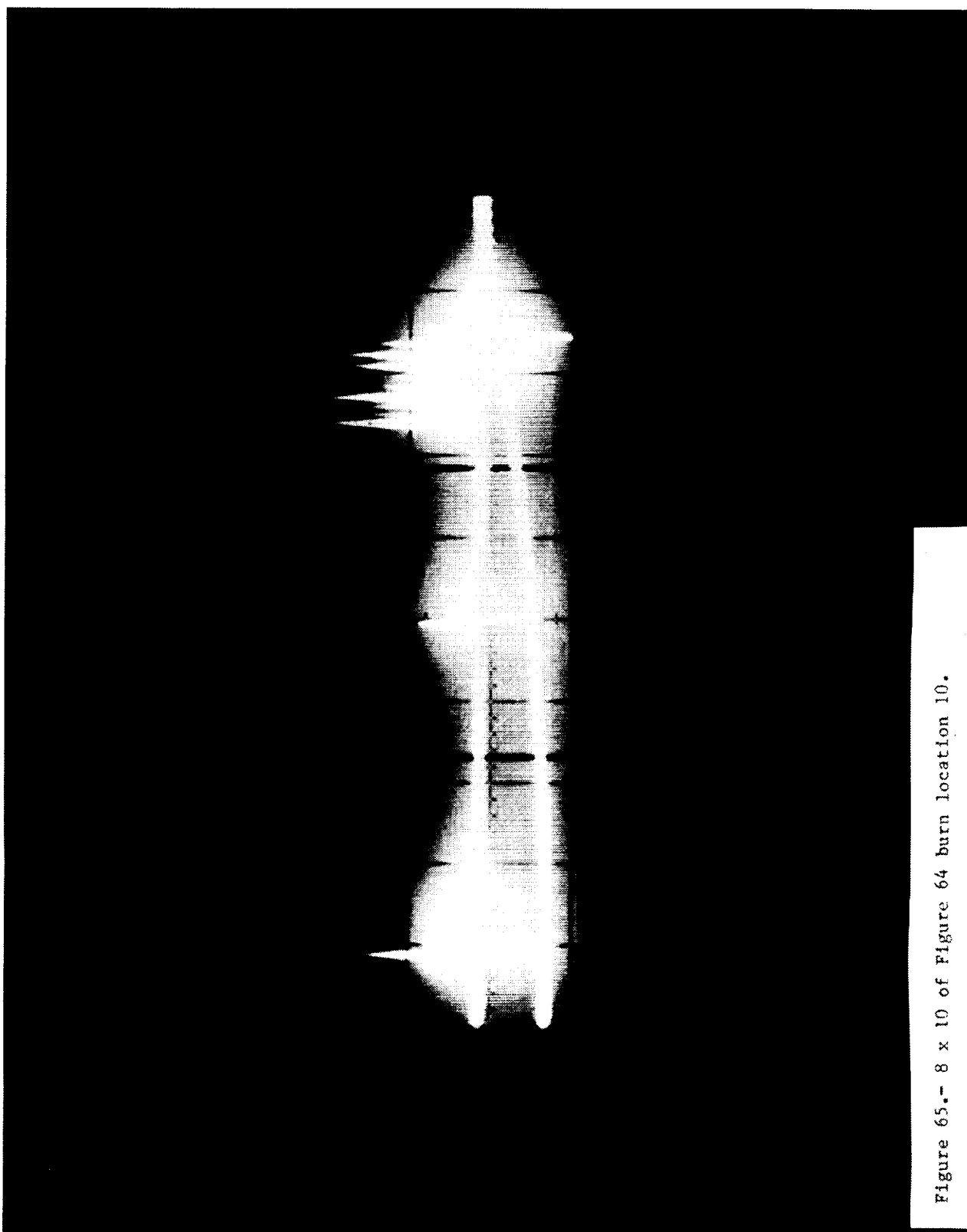
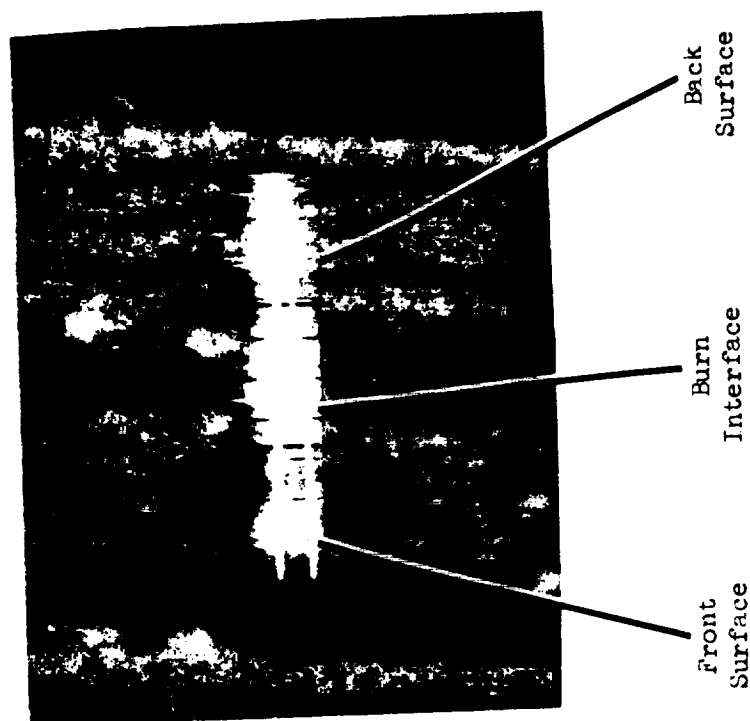


Figure 65.- 8 x 10 of Figure 64 burn location 10.



Right foot burn location 10 - 2nd degree 1/2 thickness

Skin thickness 1.05mm

Burn interface .55mm

F30B

Unfocused 20Mhz Xducer

Figure 66.- Right foot burn location 10.

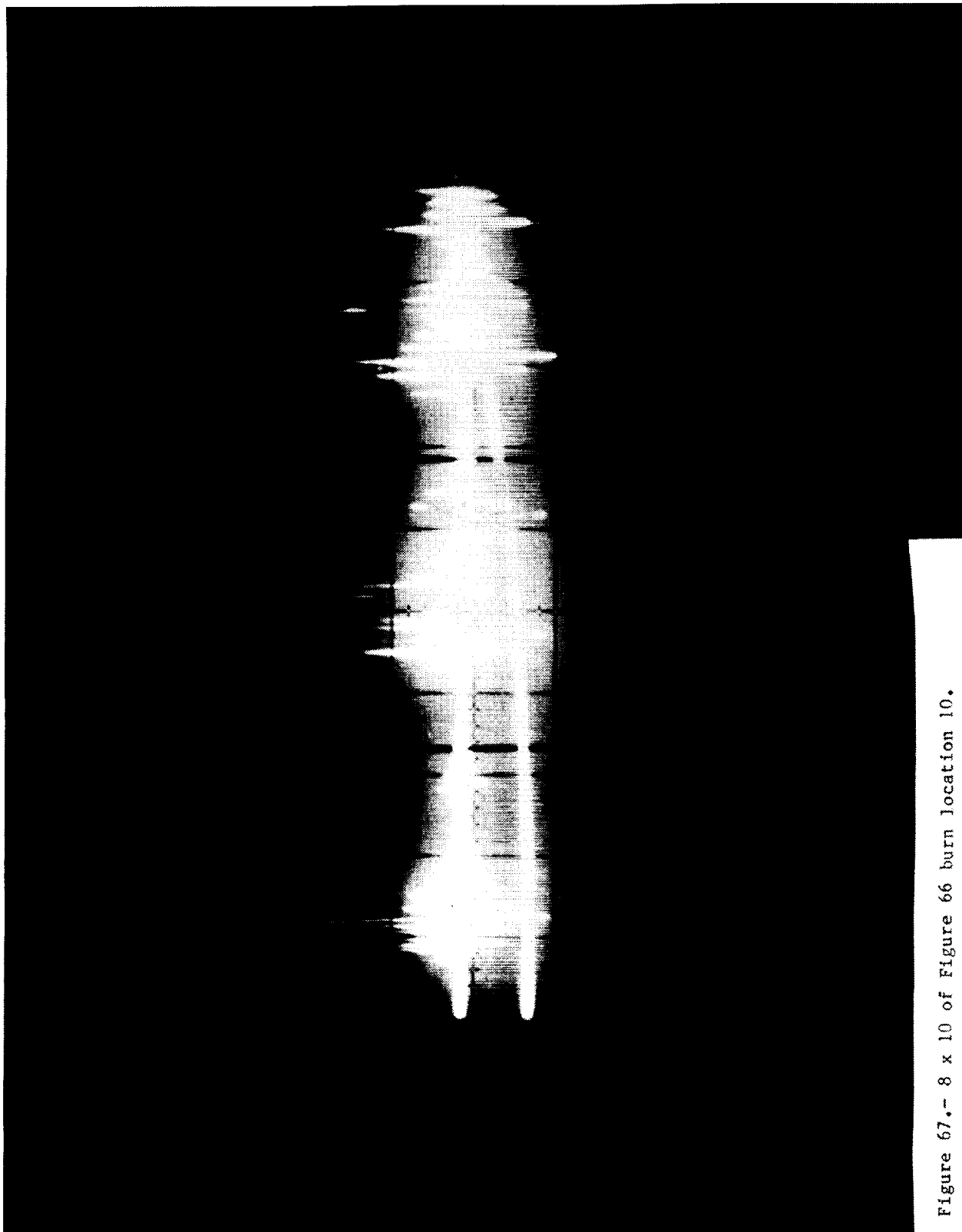
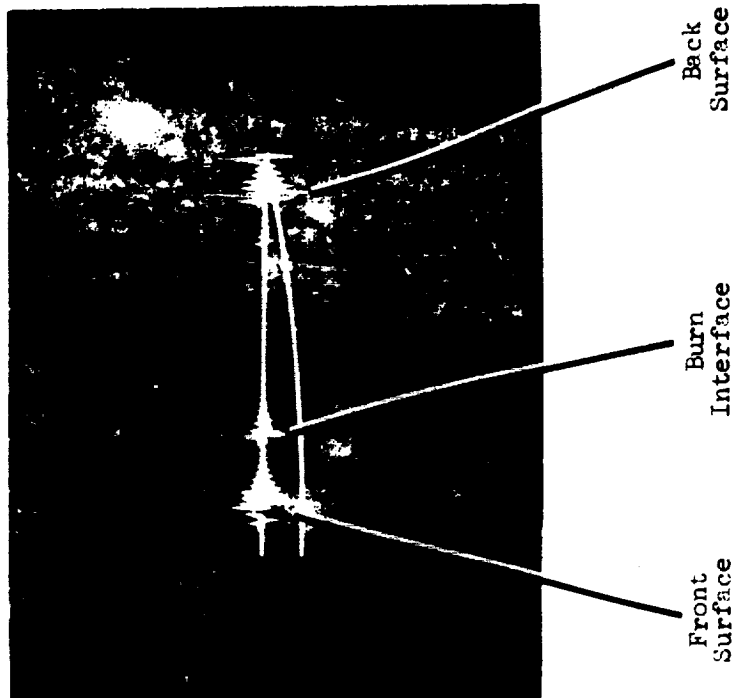


Figure 67.- 8 x 10 of Figure 66 burn location 10.



Right foot burn location 14 - 2nd degree

Skin thickness 1.1mm

Burn interface .30mm

F30B

Unfocused 20Mhz Xducer

Figure 68.- Right foot burn location 14.

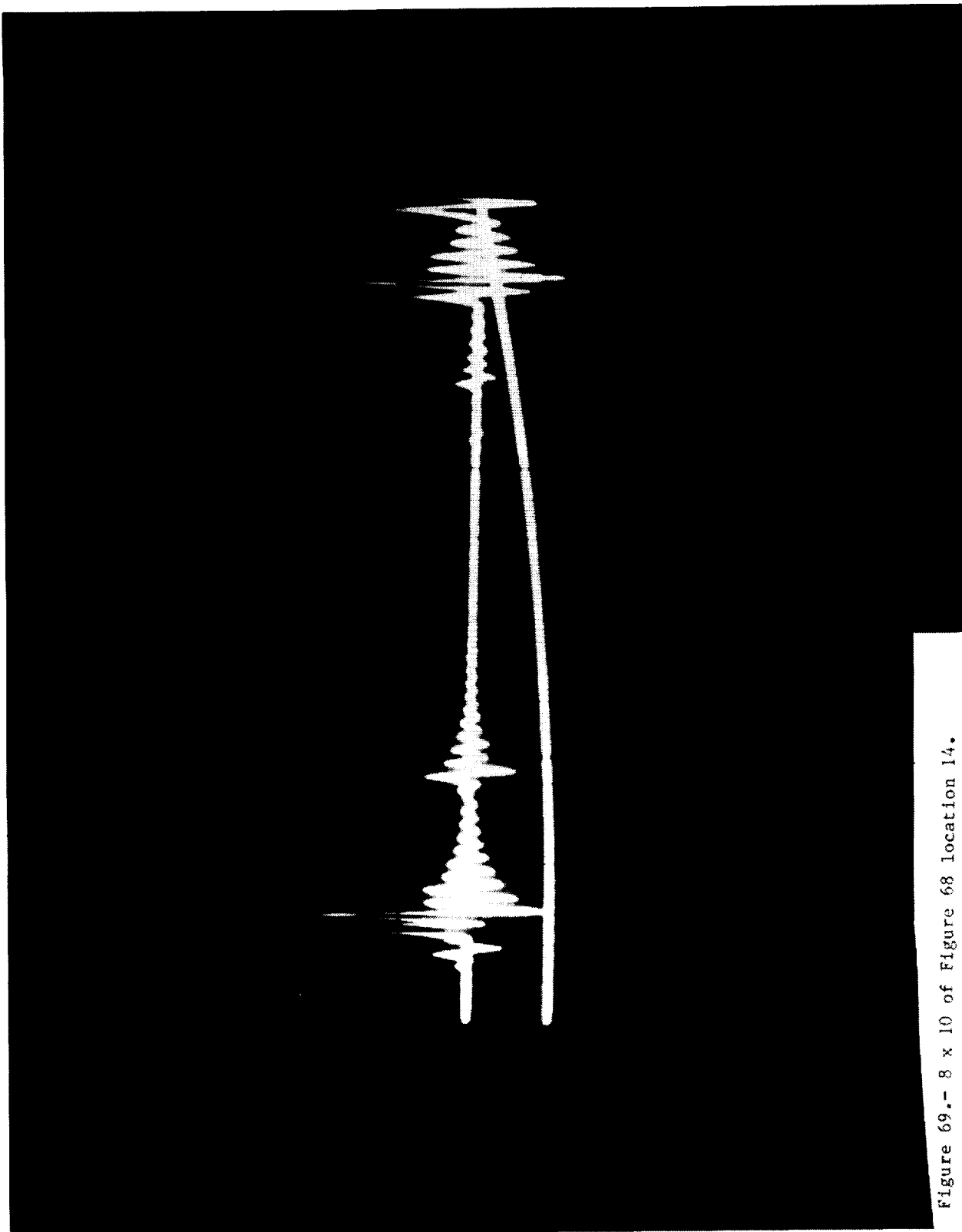
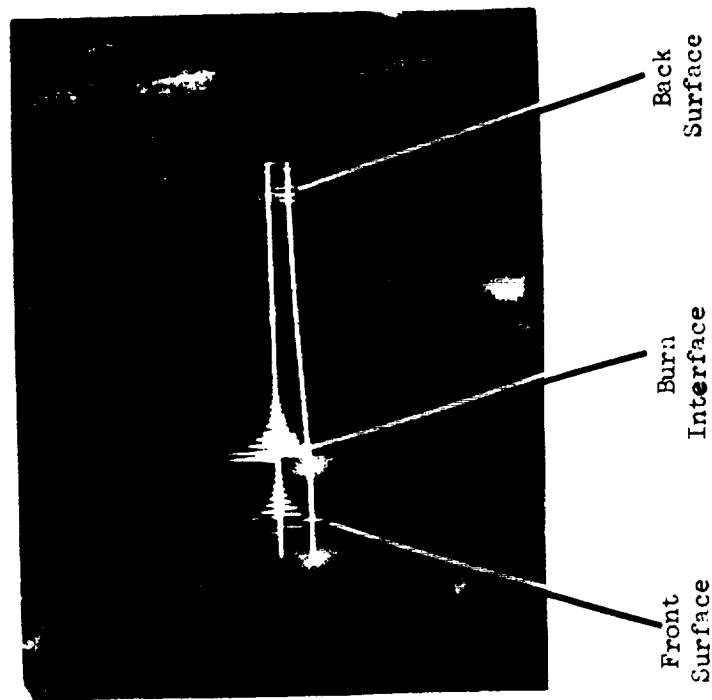


Figure 69.- 8 x 10 of Figure 68 location 14.



Right foot burn location 15 - 2nd degree

Skin thickness 1.15mm

Burn interface .25mm

F30B

Unfocused 20MHz Xducer

Figure 70.- Right foot burn location 15.

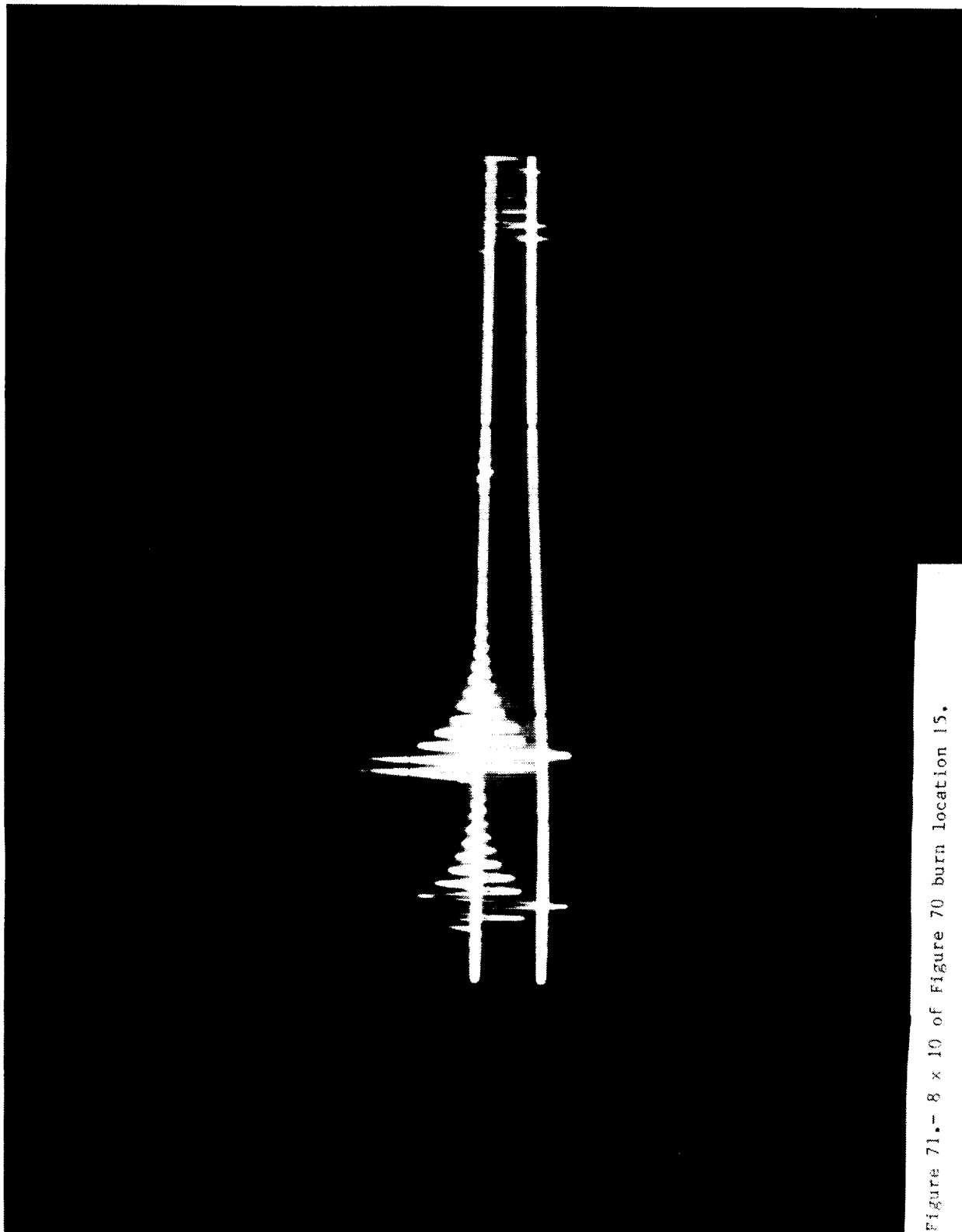
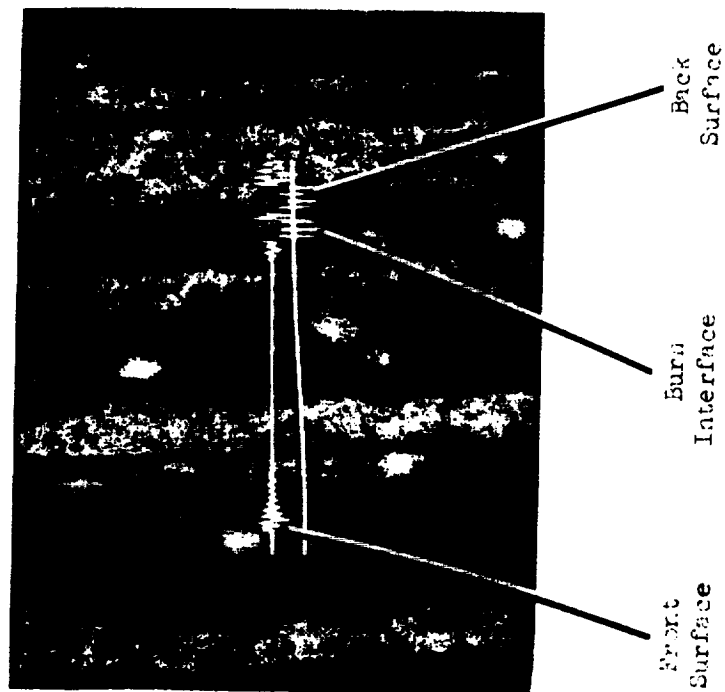


Figure 71.- 8 x 10 of Figure 70 burn location 15.



Right foot burn location 15 - 2nd degree 3/4 thickness

Skin thickness 1.15mm

Burn interface 1.05mm

F30B

Unfocused 20Mhz Xducer

Figure 72.- Right foot location of burn location 15.

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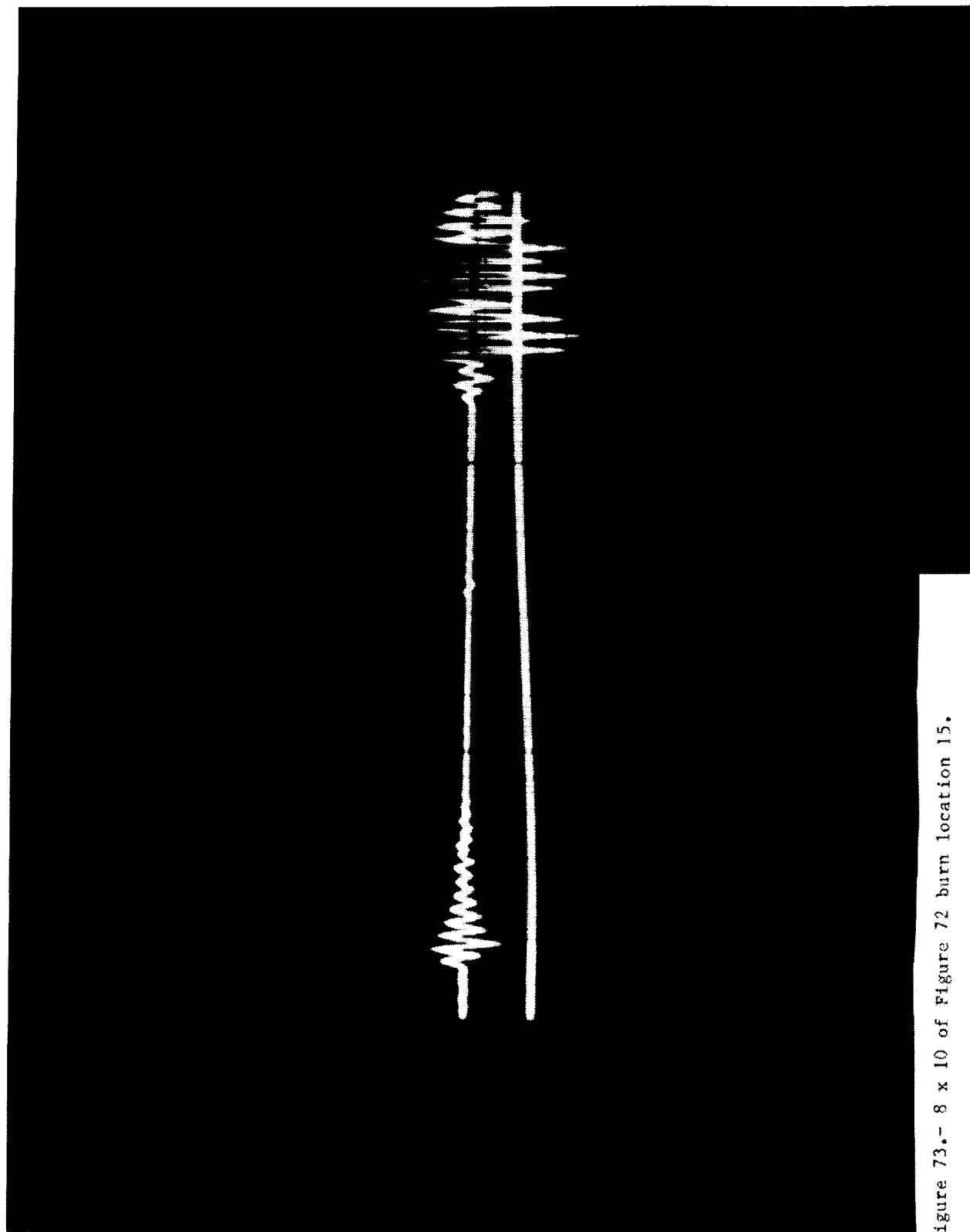
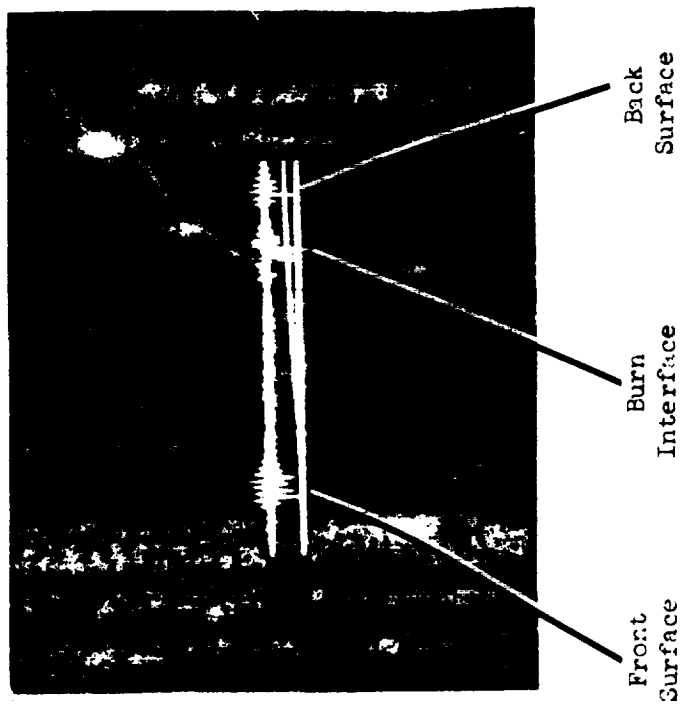


Figure 73.- 8 x 10 of Figure 72 burn location 15.



Right foot burn location 15 - 2nd degree 2/3 thickness

Skin thickness 1.1mm

Burn interface .85mm

F30B

Unfocused 20Mhz Xducer

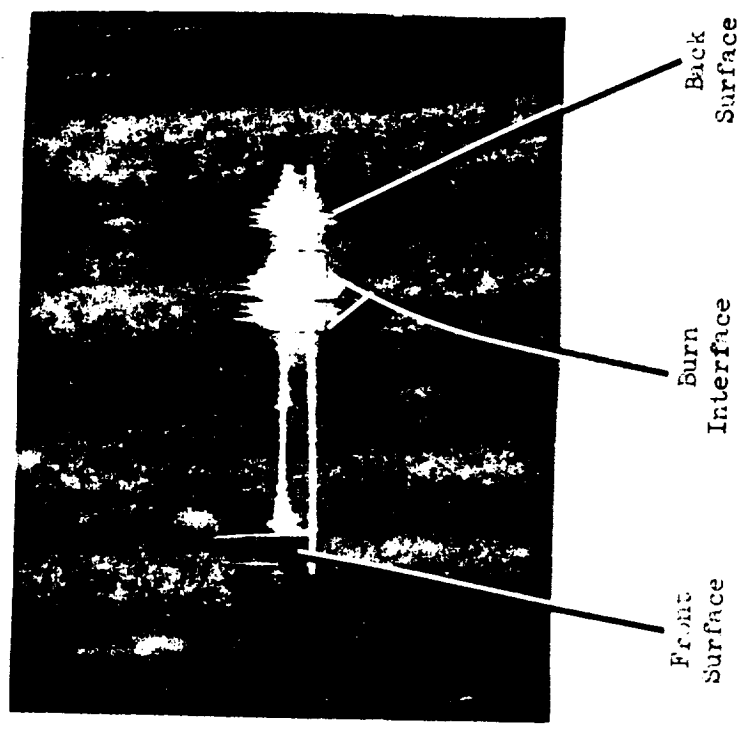
Figure 74.- Right foot burn location 15.



Figure 75.- 8 x 10 Figure 74 burn location 15.



Figure 76.- 8 x 10 of patient's foot showing burn locations.



F30B

Focused 15Mhz Xducer

Right foot burn location 1 - 2nd degree 2/3 thickness

Skin thickness 1.2mm

Burn interface .85mm

Figure 77.- Right foot burn location 1.

ORIGINAL 17410 11
OF 1000 1141 107

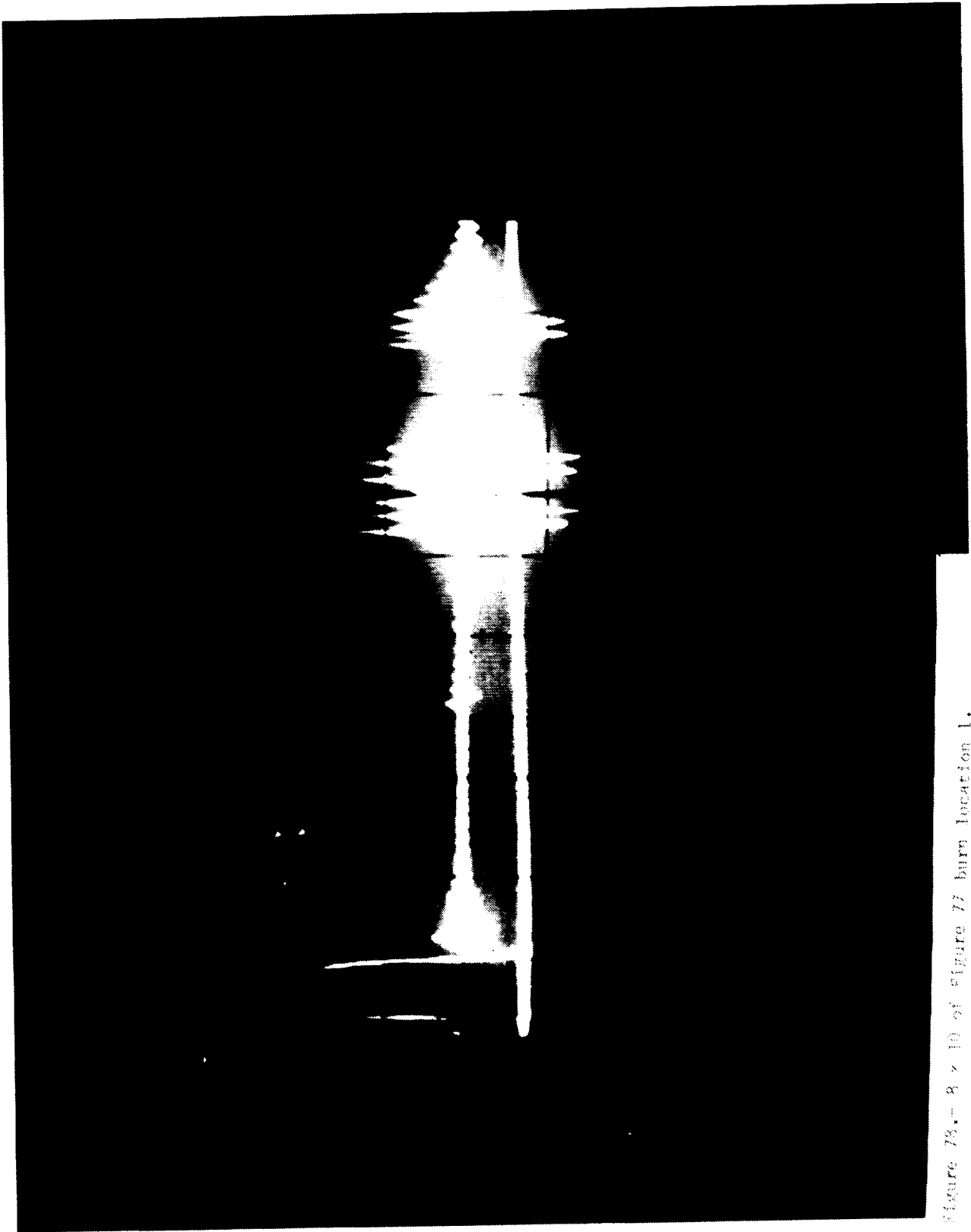
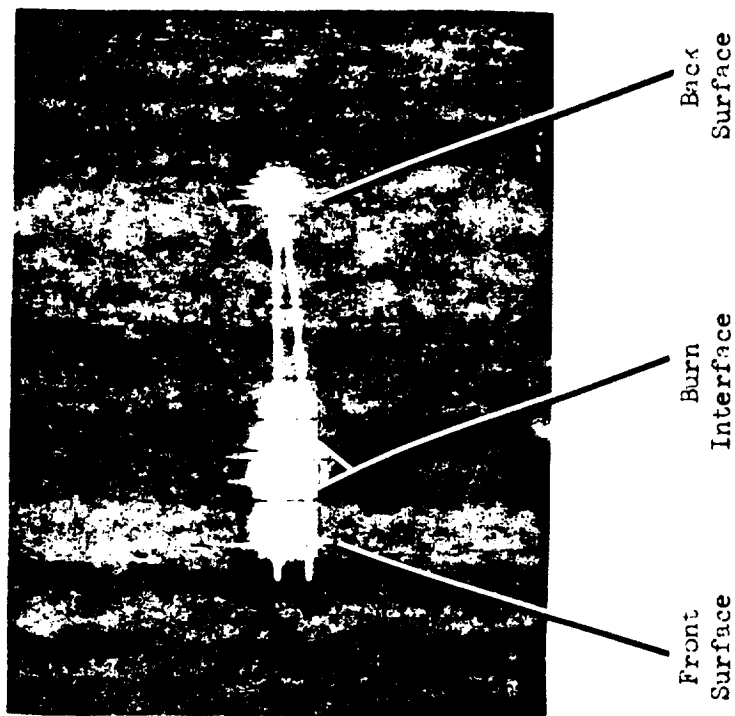


Figure 78.- 8 x 10 of figure 77 burn location 1.



Right Foot burn location 1 - 2nd degree

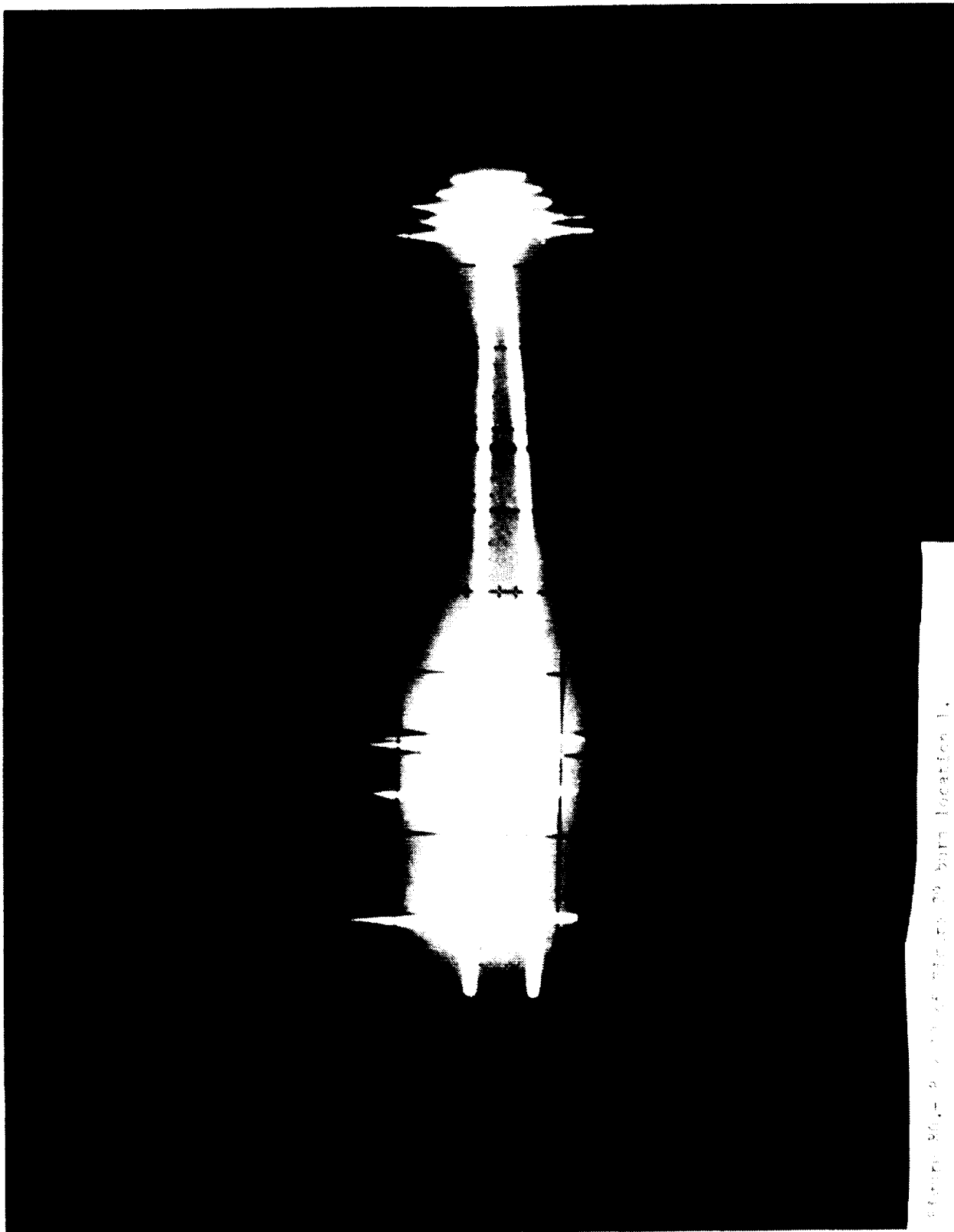
Skin thickness 1.2mm

Burn interface .25mm

F30B

Focused 15Mhz Xducer

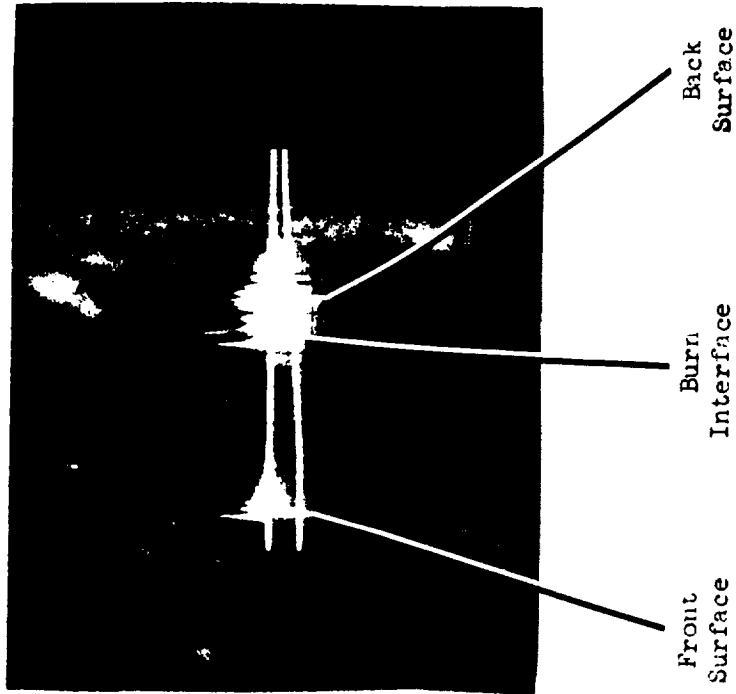
Figure 79.- Right foot burn location 1.



Sketch 20. - A view of the object to be located.

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Right foot burn location 2 - 2nd degree 2/3 thickness

Skin thickness .75mm

Burn interface .65mm

F30B

Focused 15Mhz Xducer

Figure 81.- Right foot burn location 2.

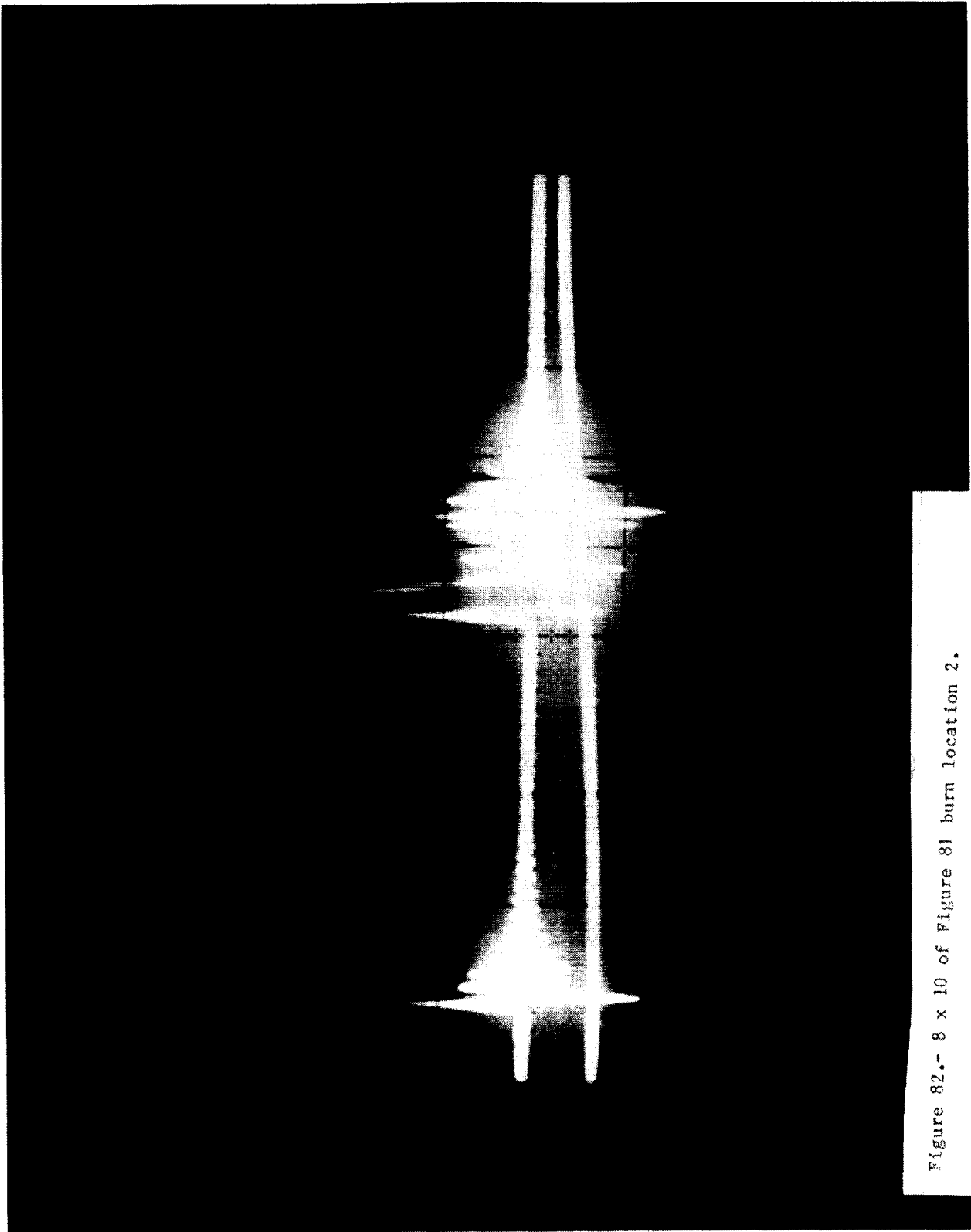
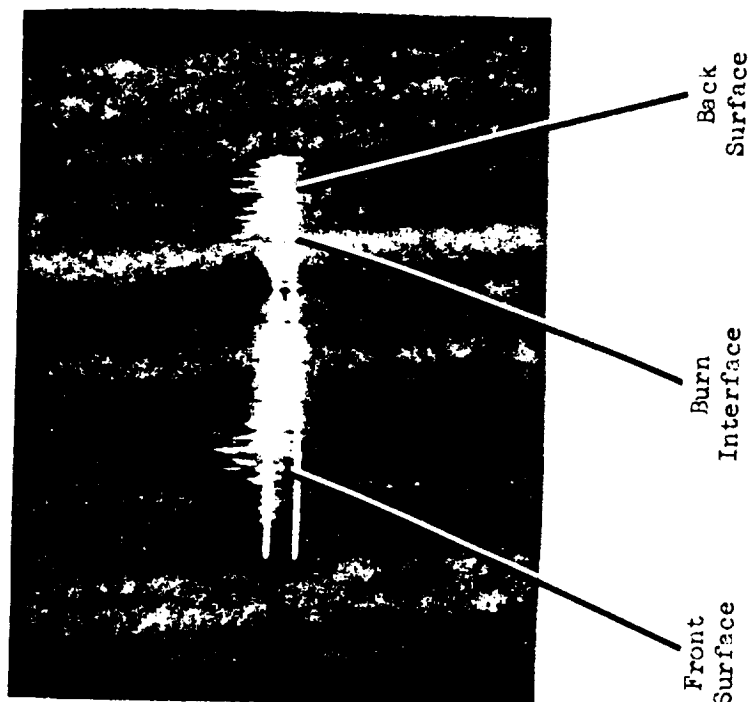


Figure 82.- 8 x 10 of Figure 81 burn location 2.

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F30B

Focused 15Mhz Xducer

Right foot burn location 1 - 2nd degree 2/3 thickness

Skin thickness 1.05mm

Burn interface .85mm

Figure 83.- Right foot burn location 1.

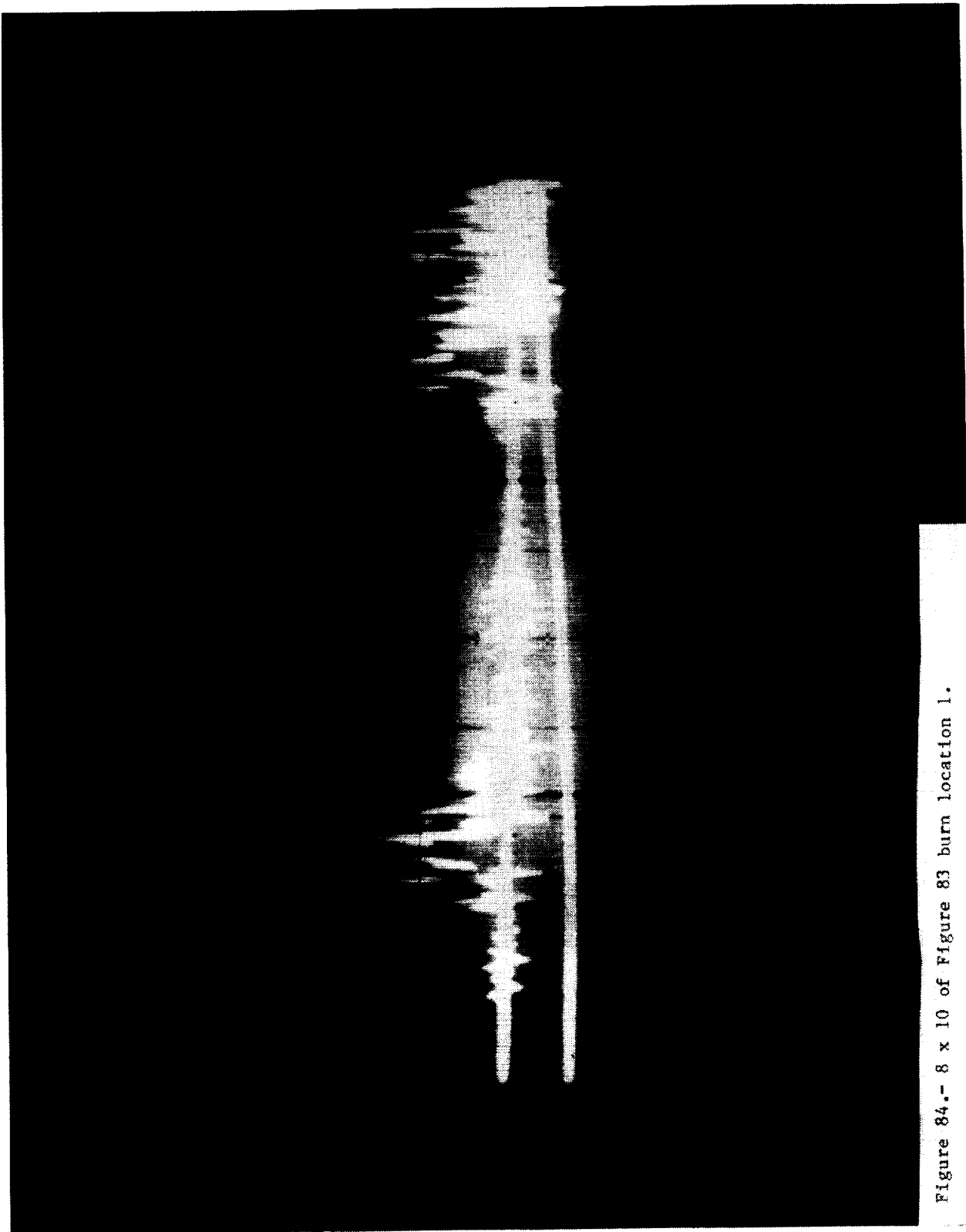
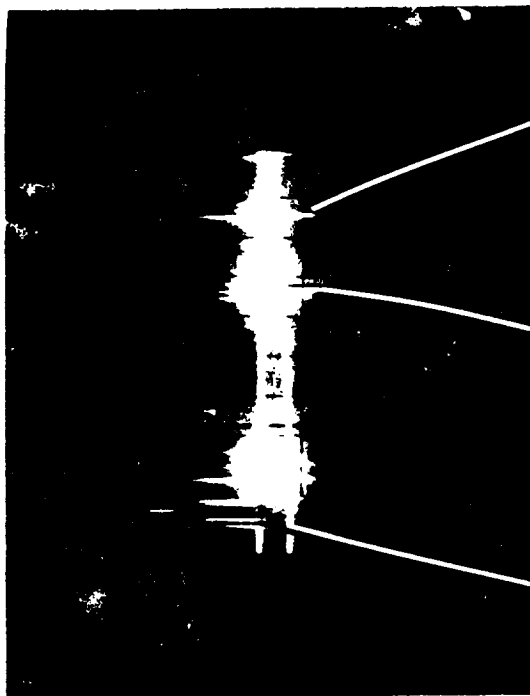


Figure 84.- 8 x 10 of Figure 83 burn location 1.



Back
Surface

Cutaneous
Structure

Front
Surface

F30B

Focused 15Mhz Xducer

Right foot - Control
Skin thickness 1.1mm

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Figure 85.- Control right foot.

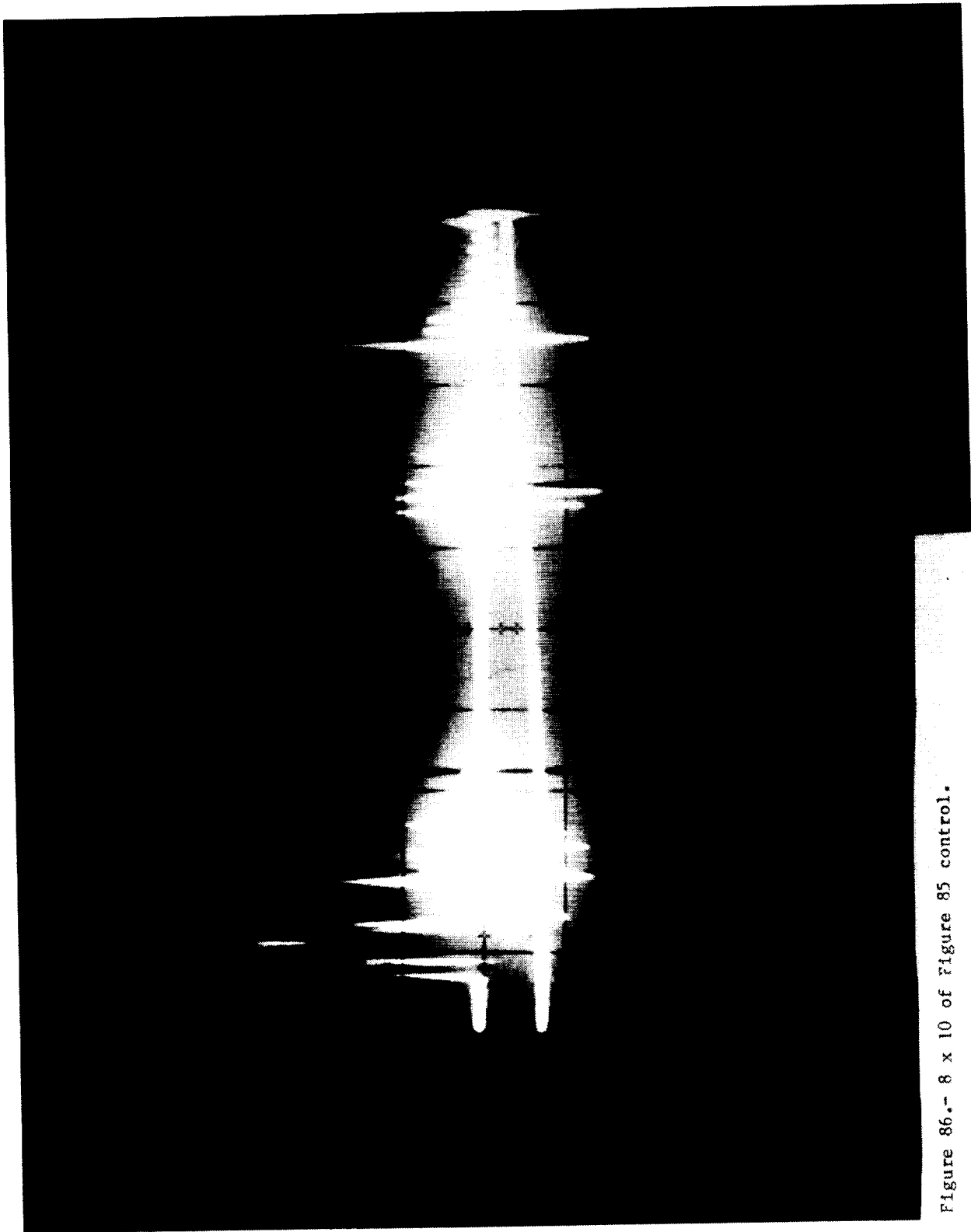
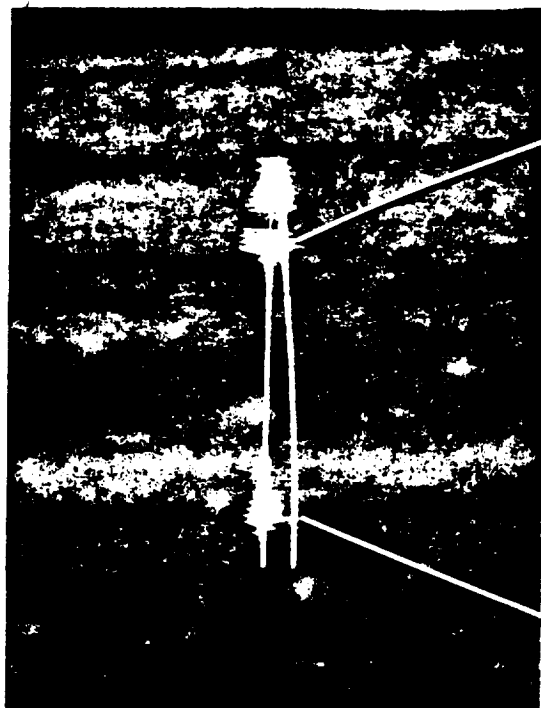


Figure 86.- 8 x 10 of Figure 85 control.



Back
Surface

Front
Surface

Right foot burn location 3 - full thickness

Burn interface 1.1mm

F30B

Focused 15Mhz Xducer

Figure 87.- Right foot burn location 3.

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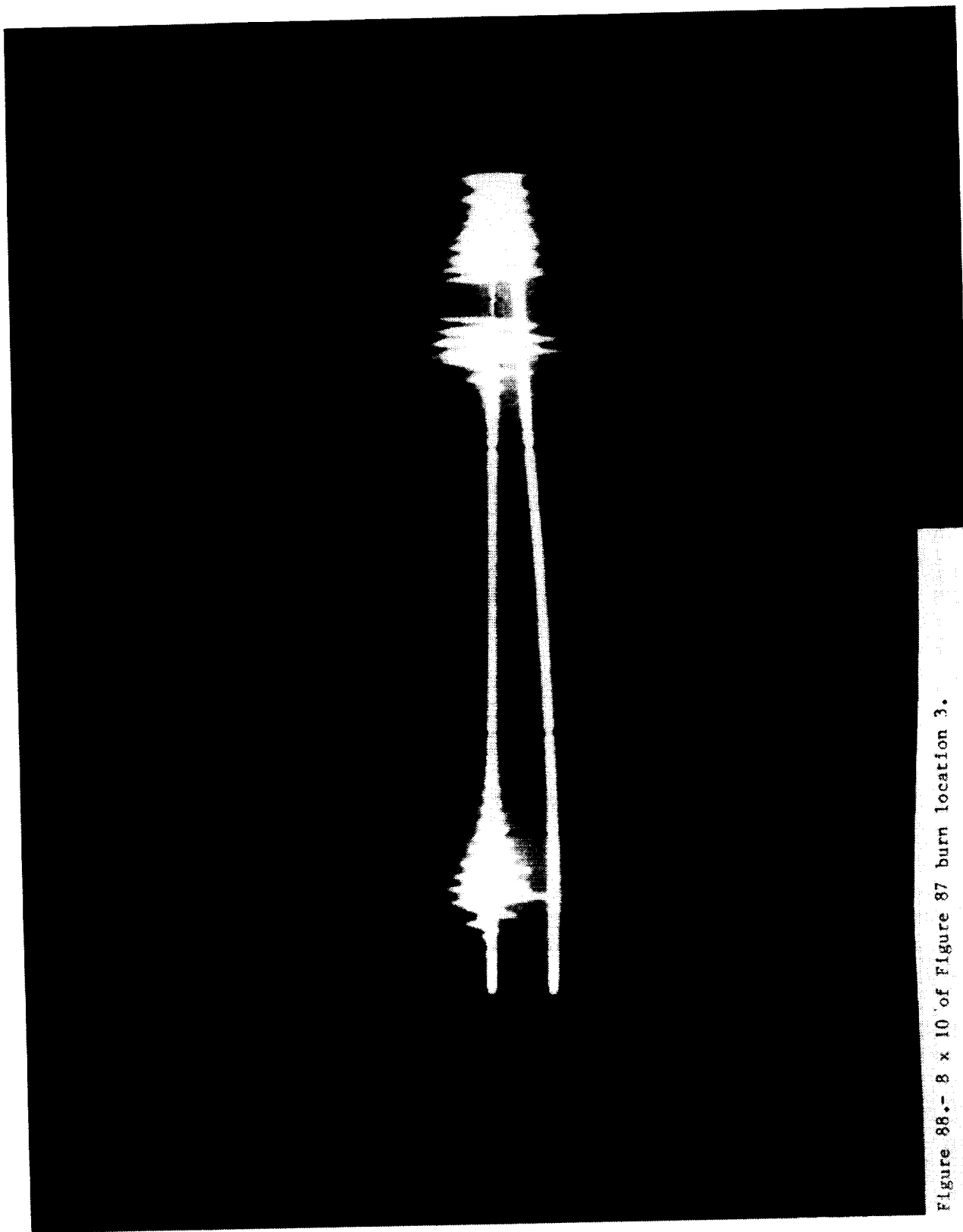
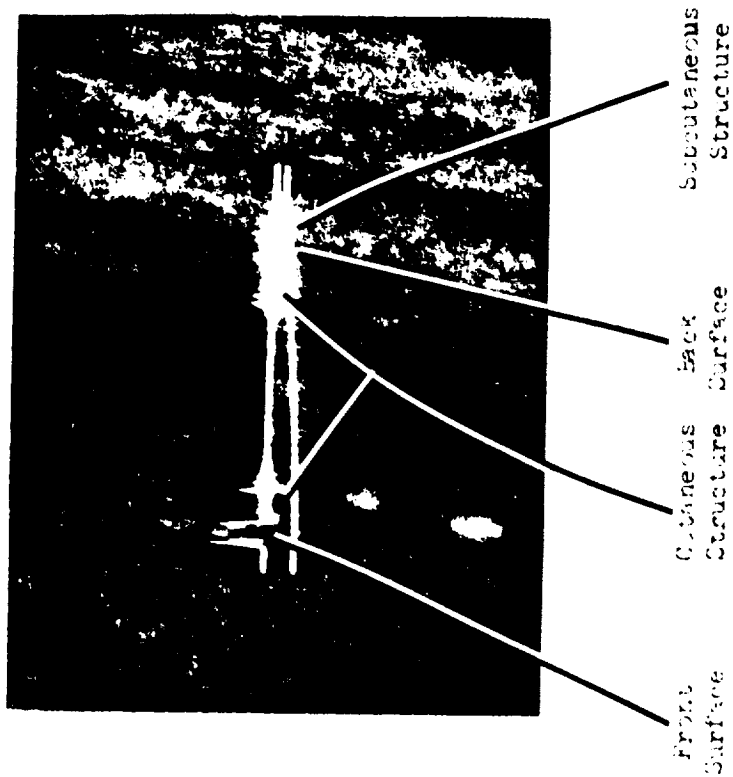


Figure 88.- 8 x 10 of Figure 87 burn location 3.

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Right foot - Control

Mean thickness 1.65mm

F30B

Focused 15Mhz Xducer

Figure 89.- Control right foot.

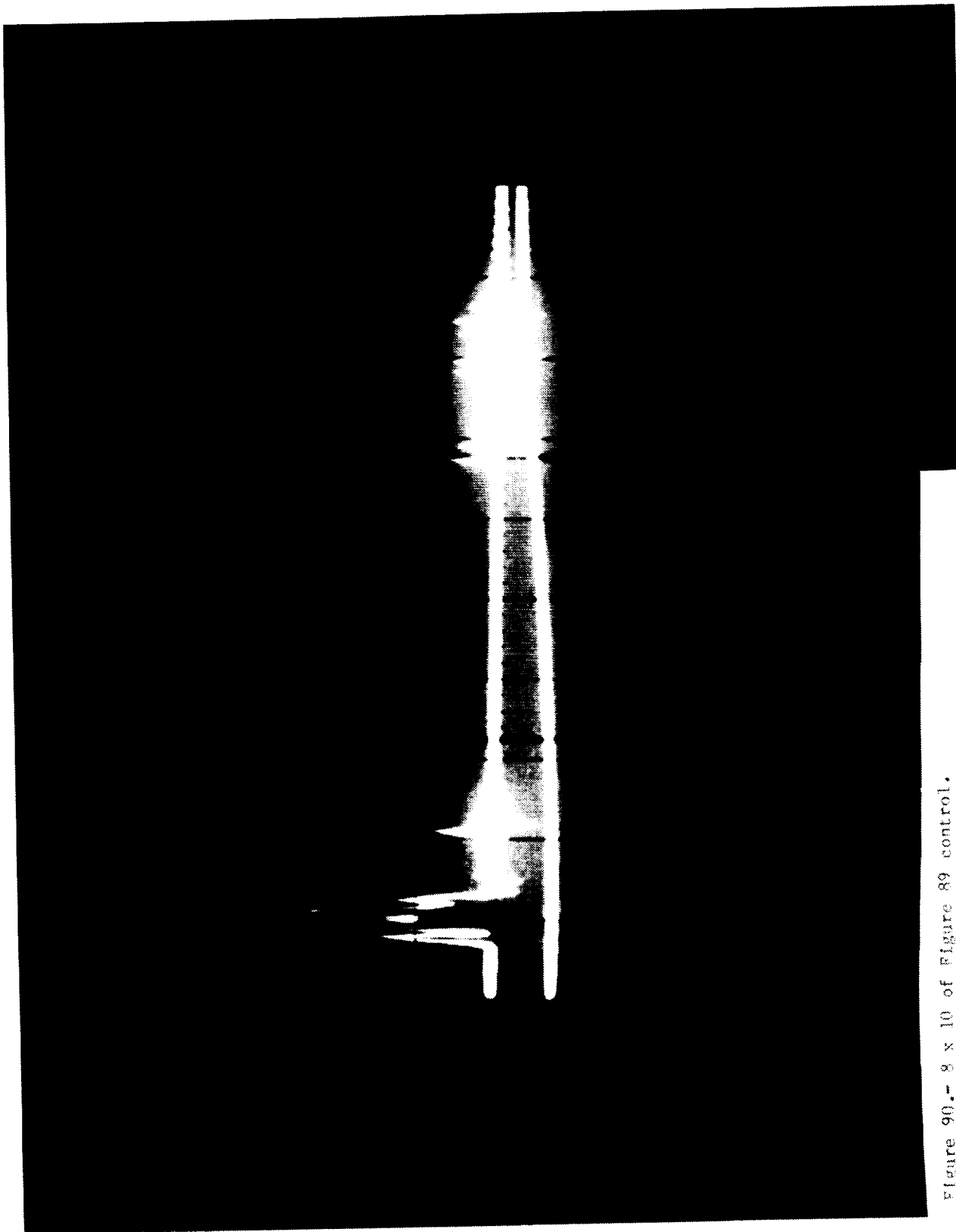


Figure 90.- 8 x 10 of Figure 89 control.

NASA

1-88-760



Figure 91.- Sketch of burn locations.

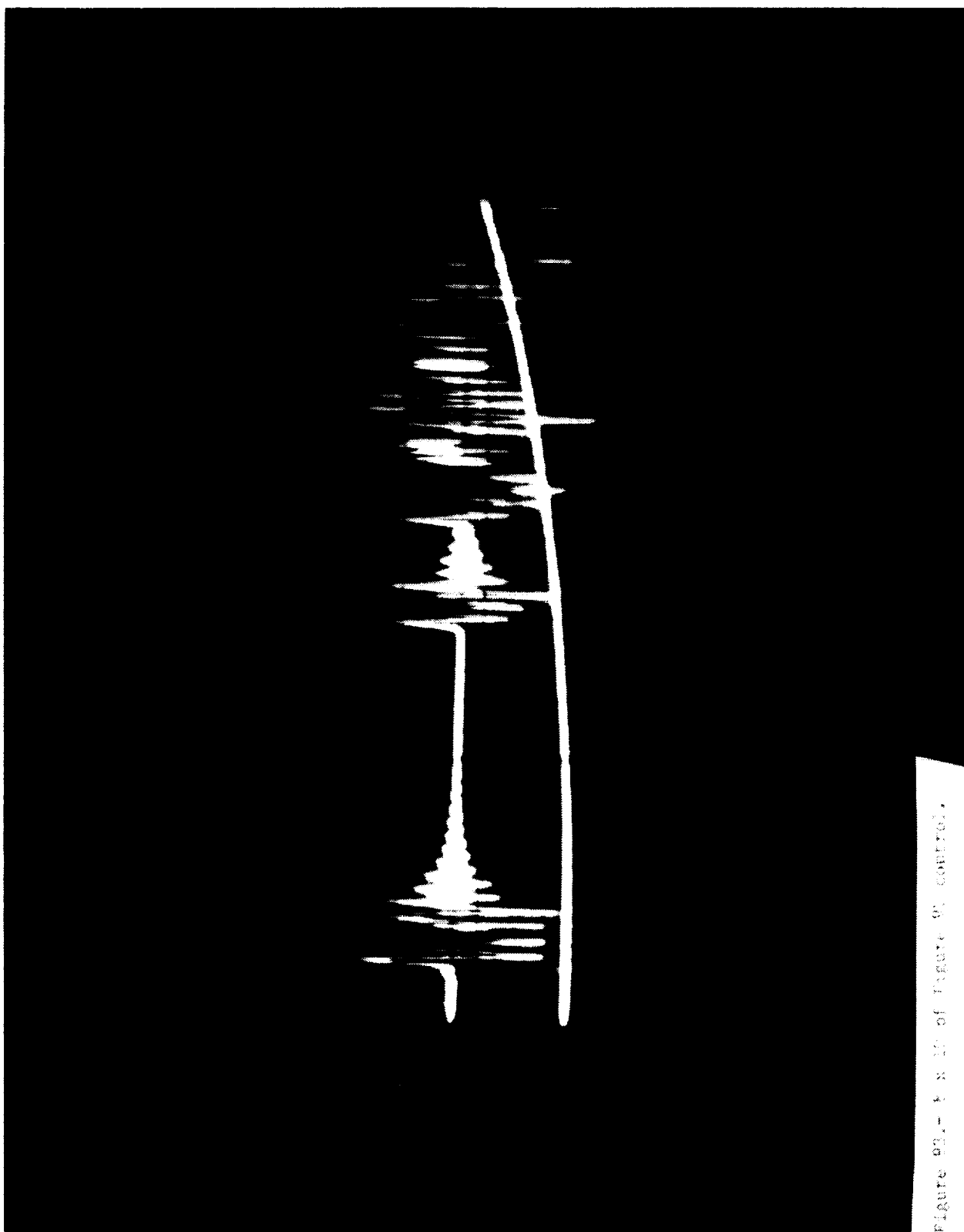
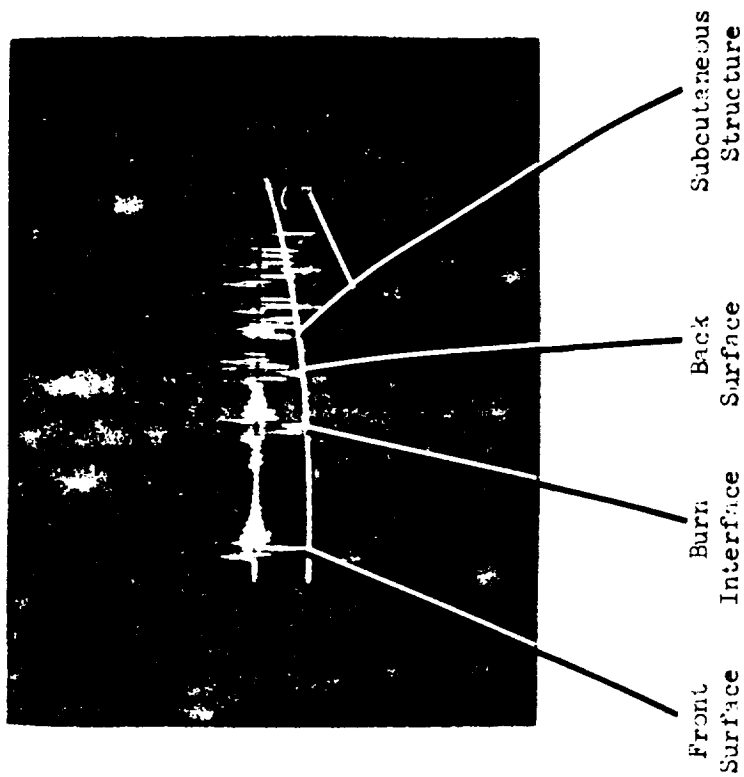


FIGURE 92.- A X 10 OF TAPE IN CONTROL.



Left leg between burn location 1x2 - 2nd degree 2/3 thickness

Skin thickness .70mm edema or change in sound velocity

Burn interface .45mm

M30W

Focused 15KHz Xducer

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Figure 94.- Left leg between burn locations 1 and 2.

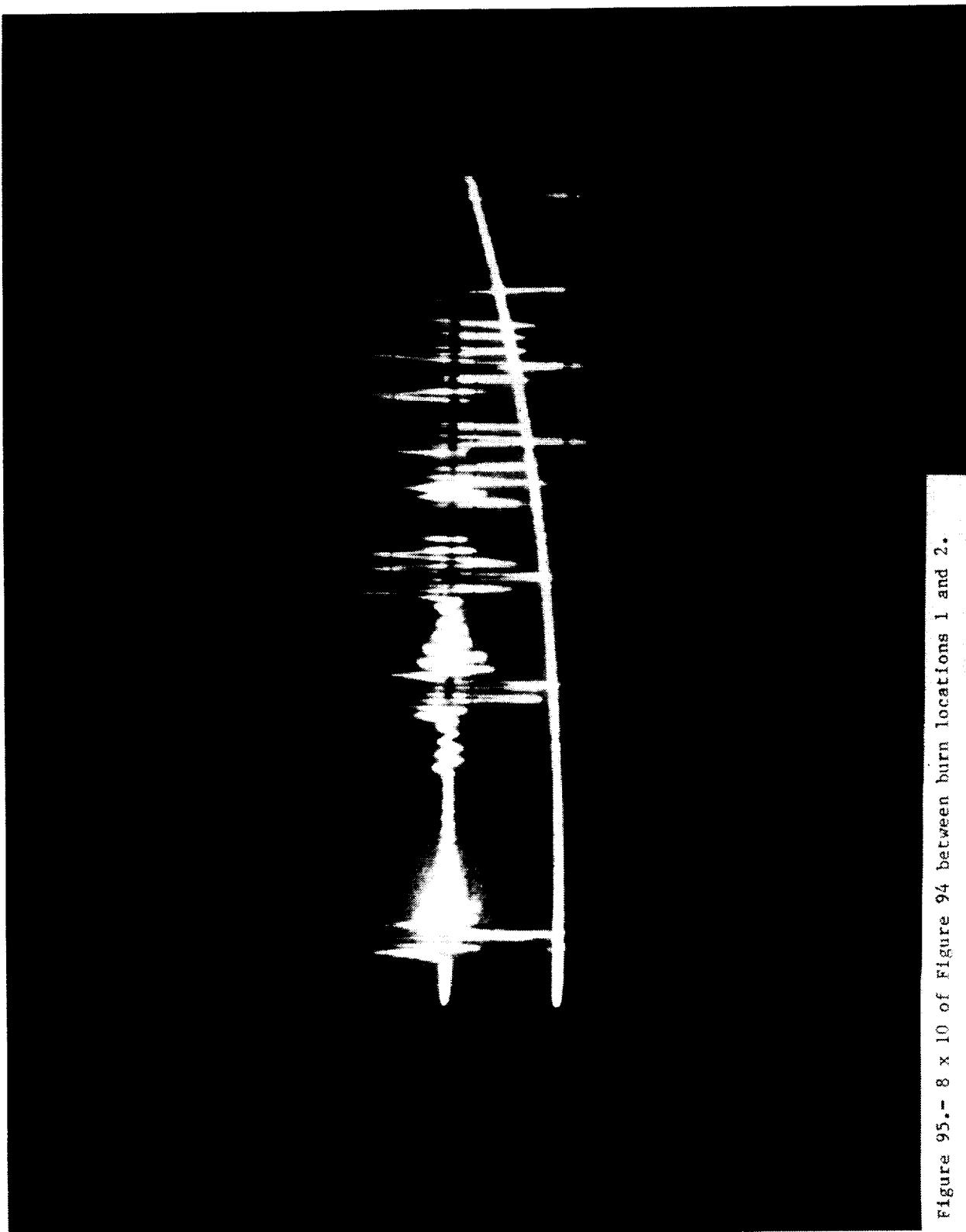
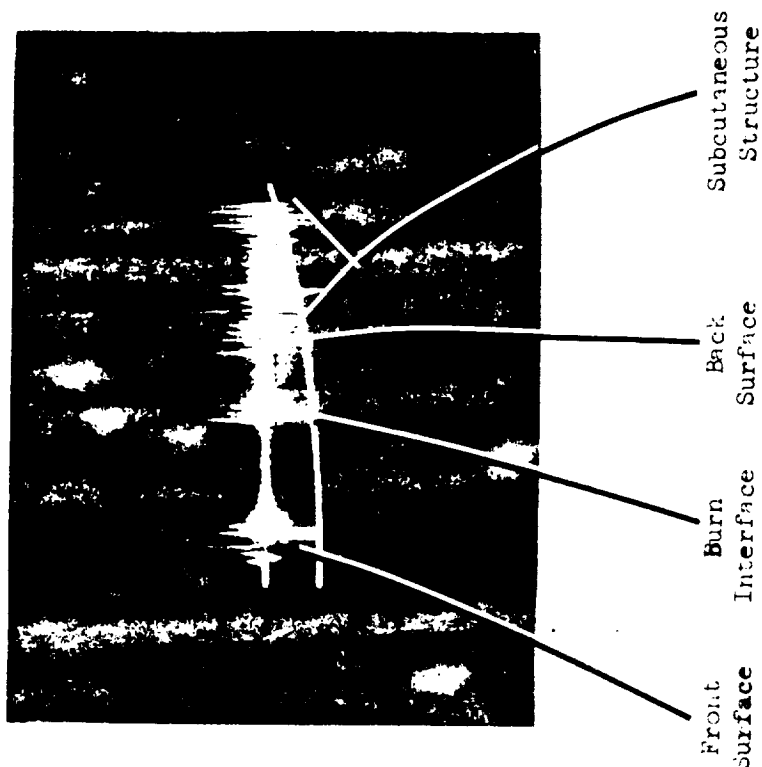


Figure 95.- 8 x 10 of Figure 94 between burn locations 1 and 2.



Left leg between burn location 1 & 2 - 2nd degree 2/3 thickness

Skin thickness .70mm edema or change in sound velocity

Burn interface .45mm

M30W

Focused 15Mhz Xanucer

Figure 96.- Left leg between burn locations 1 and 2.

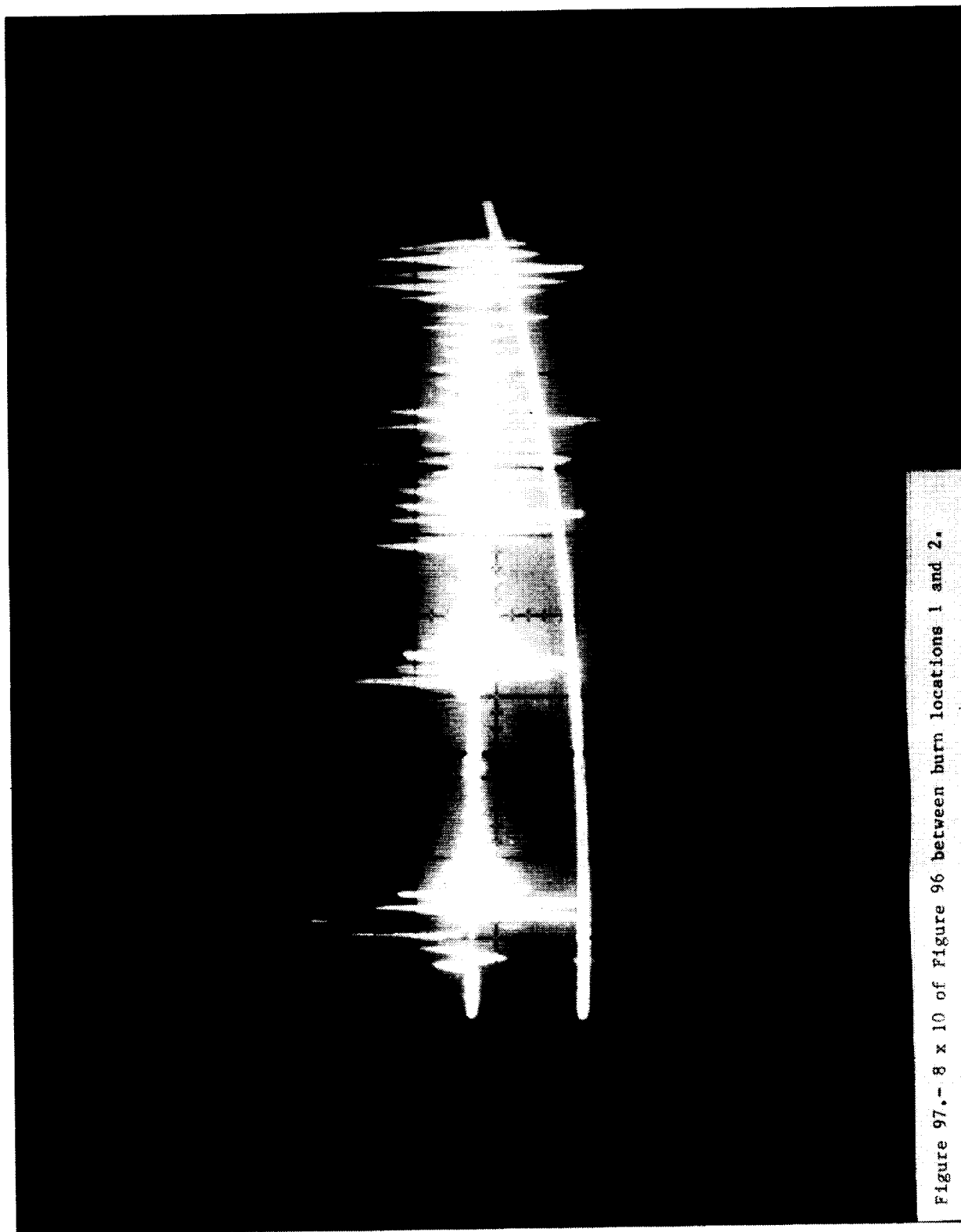
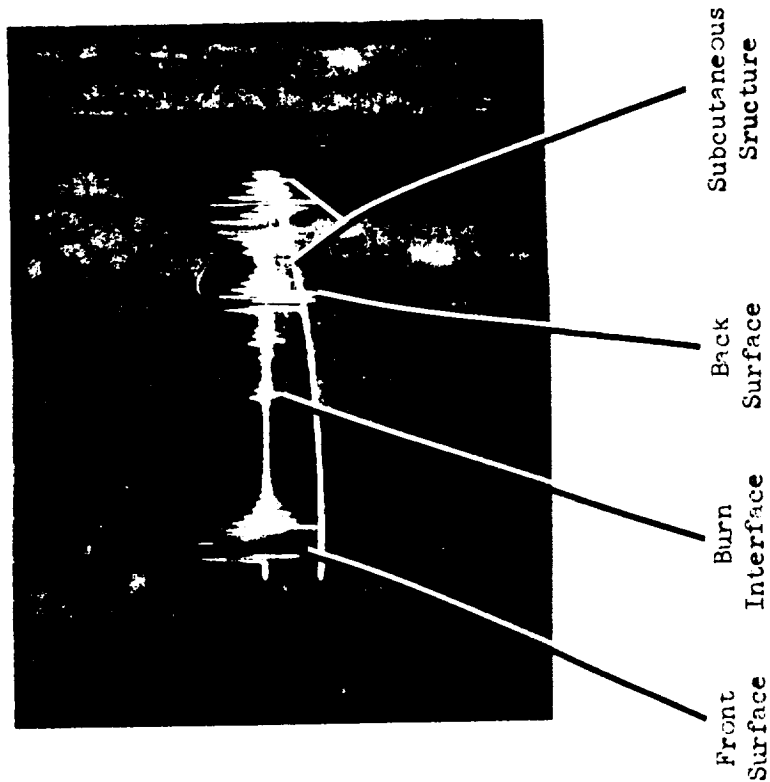


Figure 97.- 8 x 10 of Figure 96 between burn locations 1 and 2.



Left leg burn location 1 - 2nd degree 2/3 thickness Pattern indicates strong potential for degeneration into a full thickness burn.

Skin thickness .80mm edema or change in sound velocity

Burn interface .55mm

M30W

Focused 15Mhz Xducer

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Figure 98.- Left leg burn location 1.

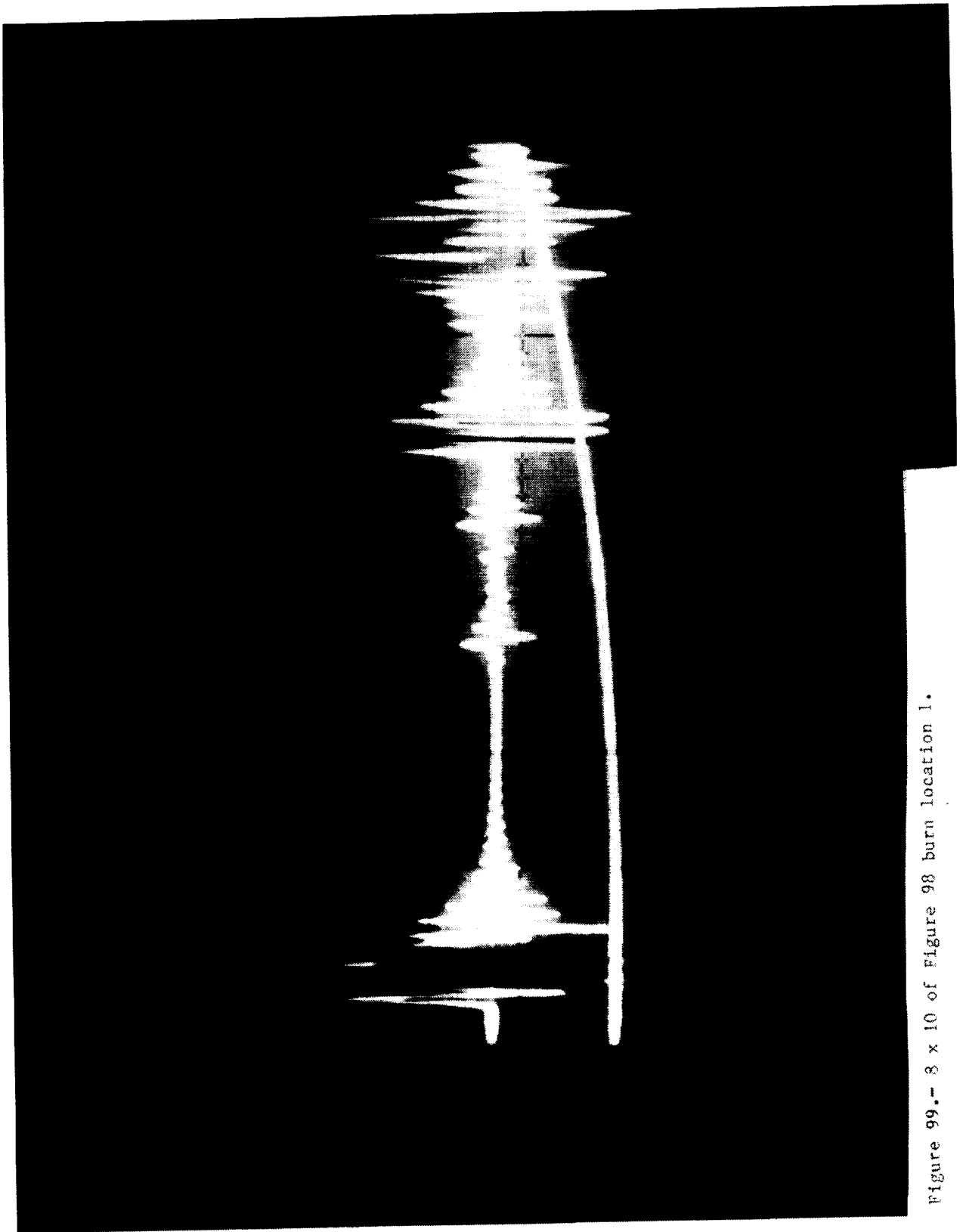
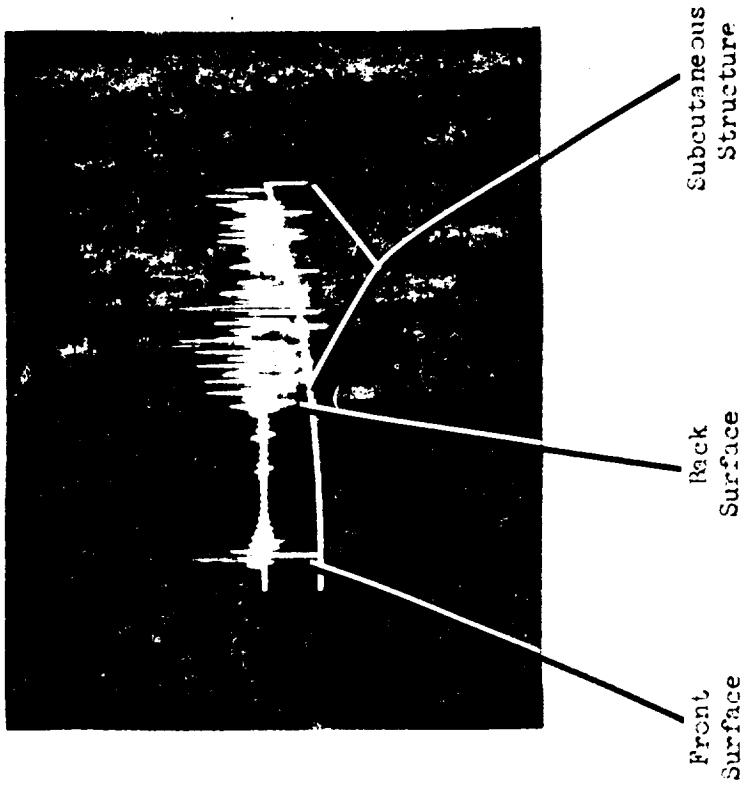


Figure 99.- 3 x 10 of Figure 98 burn location 1.

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Control - left leg

Skin thickness .55mm

M30W

Focused 15Mhz Xducer

Figure 100.- Control left calf.

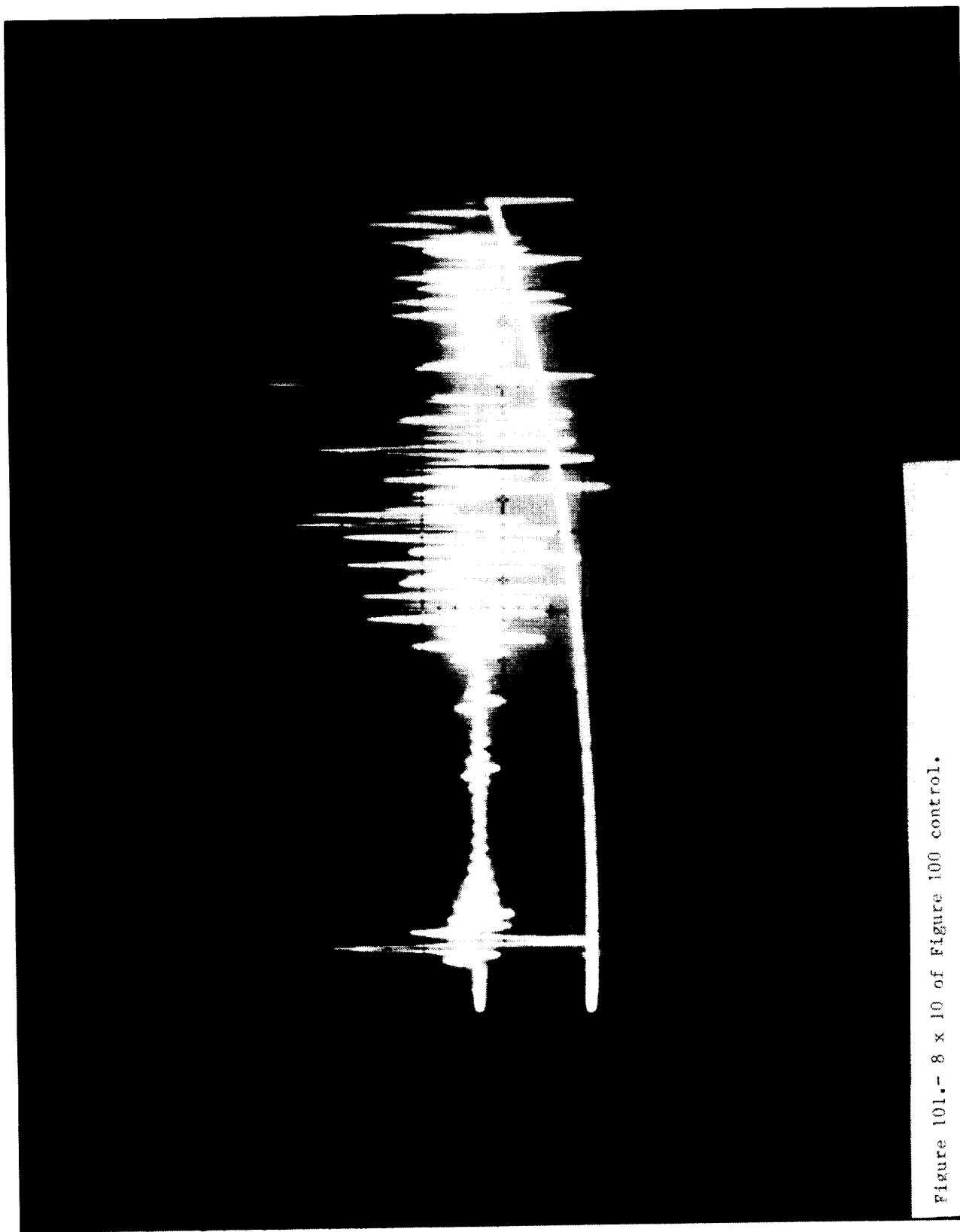
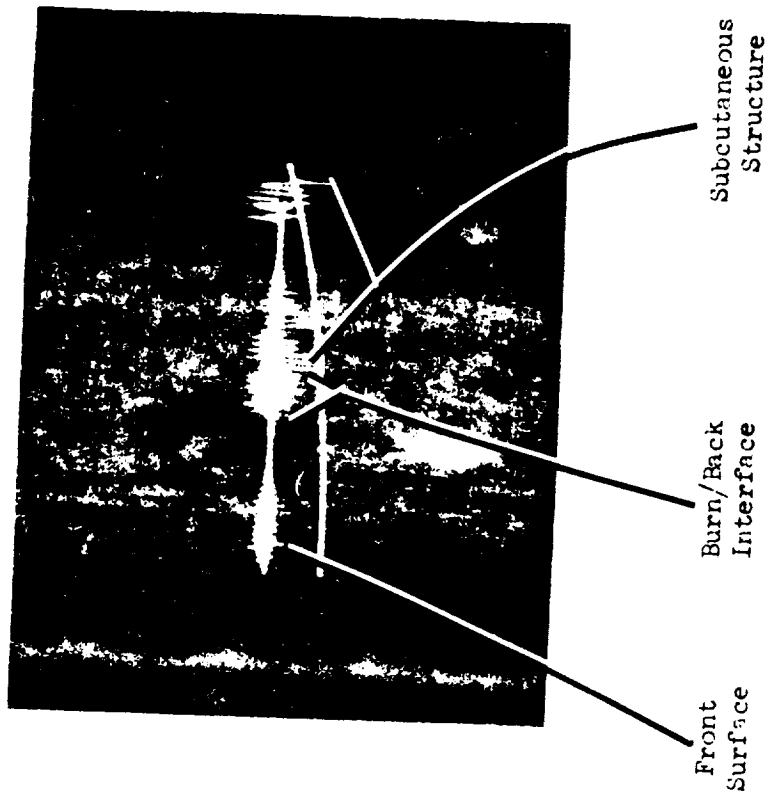


Figure 101.- 8 x 10 of Figure 100 control.



Left calf burn location 3 - deep dermal over the span of the transducer there is substantial 3rd degree component
 Burn/Back interface .55 - .70 mm
 M30W
 Focused 15Mhz Xducer

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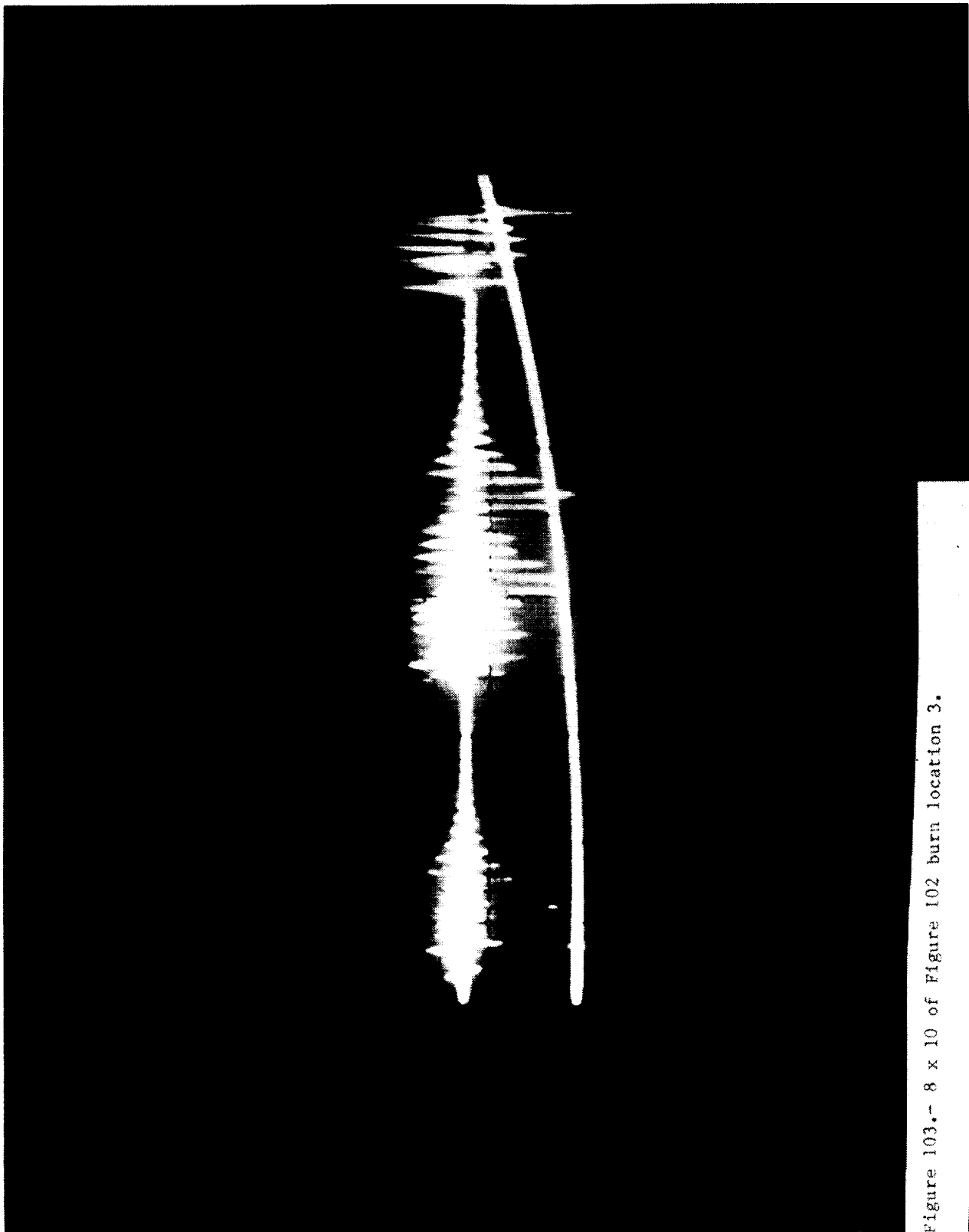
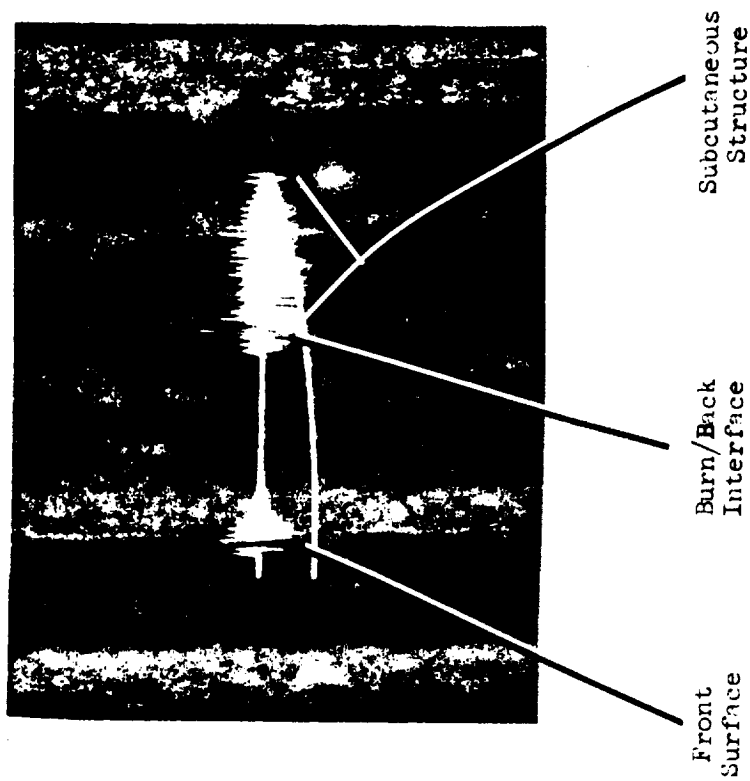


Figure 103.- 8 x 10 of Figure 102 burn location 3.

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Left calf burn location 3 - 3rd degree

Burn interface .75mm edema or change in sound velocity

M30W

Focused 15Mhz Xducer

Figure 104.- Left calf burn location 3.

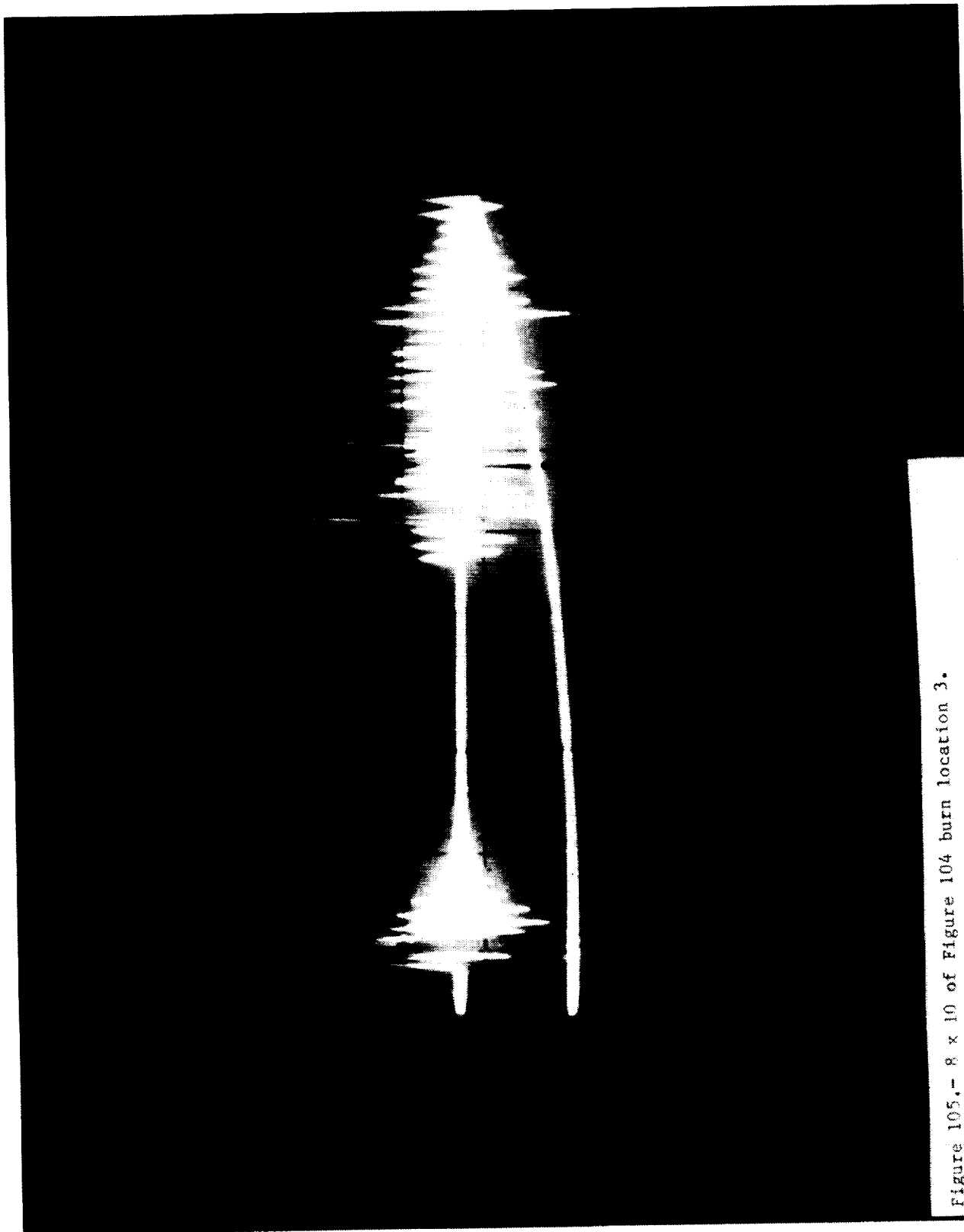
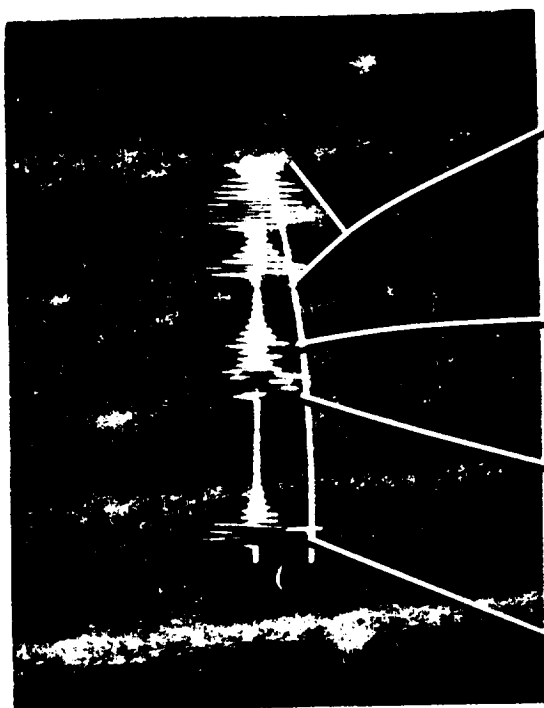


Figure 105.- 8 x 10 of Figure 104 burn location 3.



Front Surface

Burn Interface

Back Surface

Subcutaneous Structure

Right calf burn location 3 - deep dermal

Skin thickness .70mm edema or change in sound velocity

Burn interface .60mm

M30W

Focused 15Mhz Xducer

Figure 106.- Right calf burn location 3.

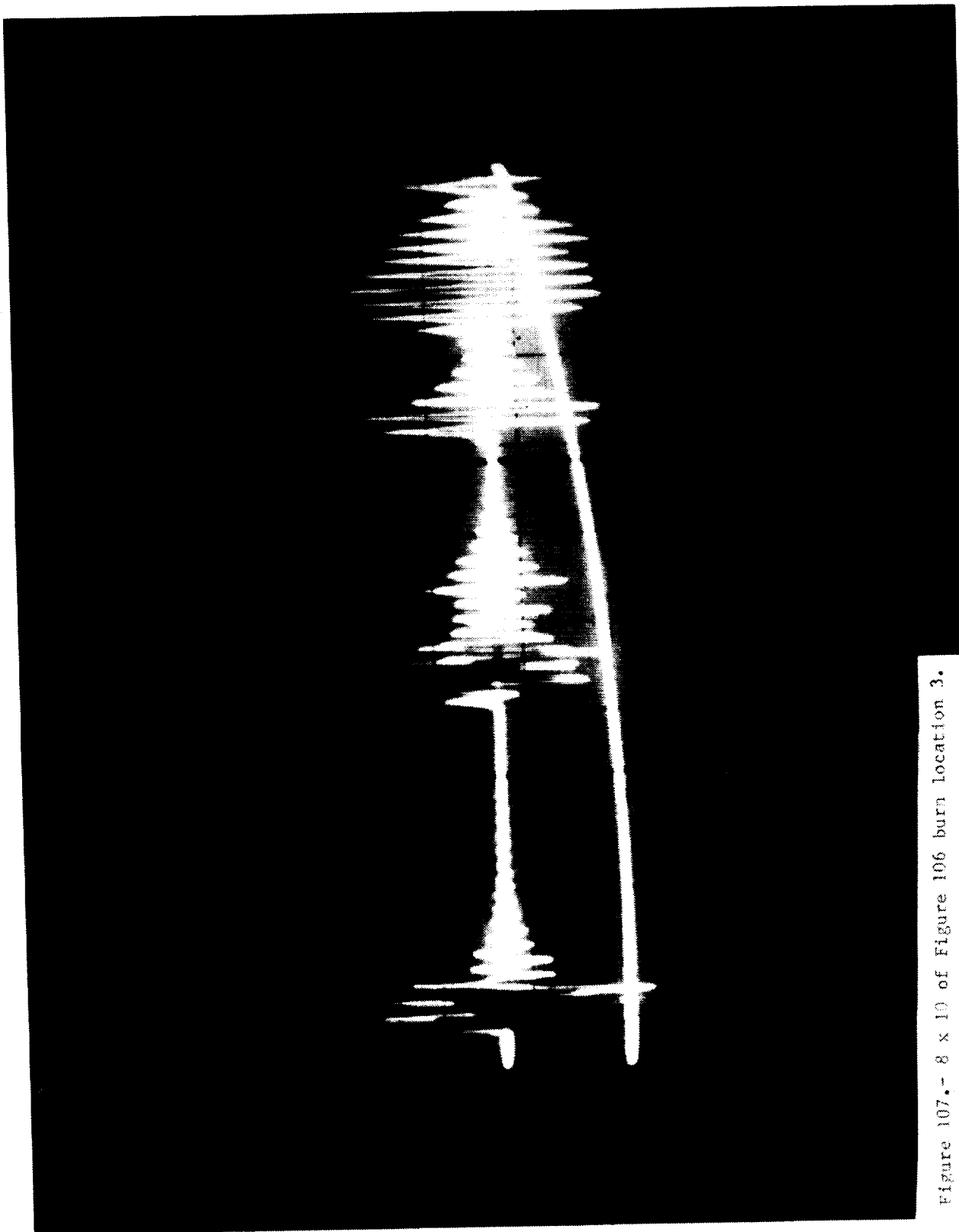
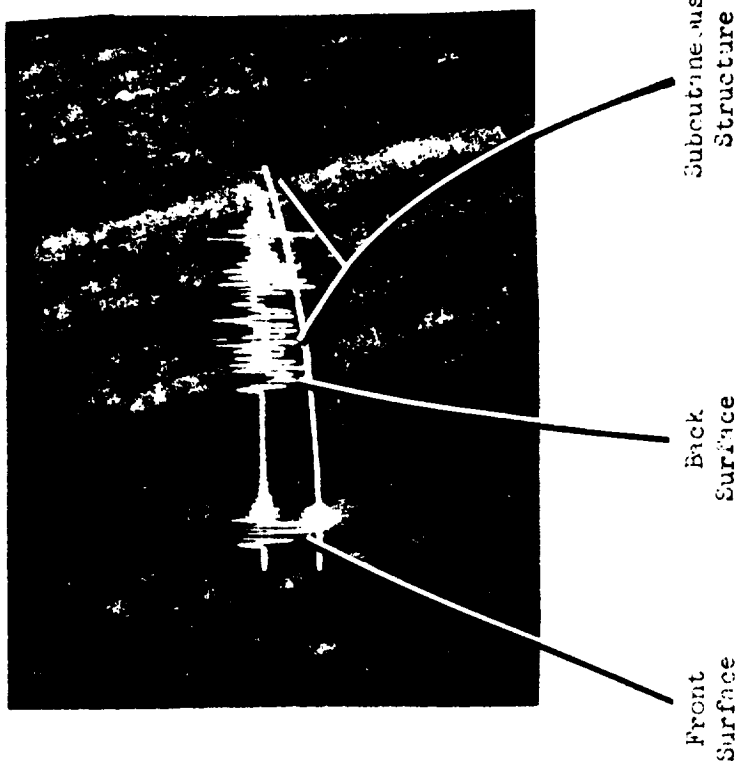


Figure 107.- 8 x 10 of Figure 106 burn location 3.



Control - right calf

Skin interface .55mm

M30W

Focused 15Mhz Xducer

Figure 108.- Control right calf.

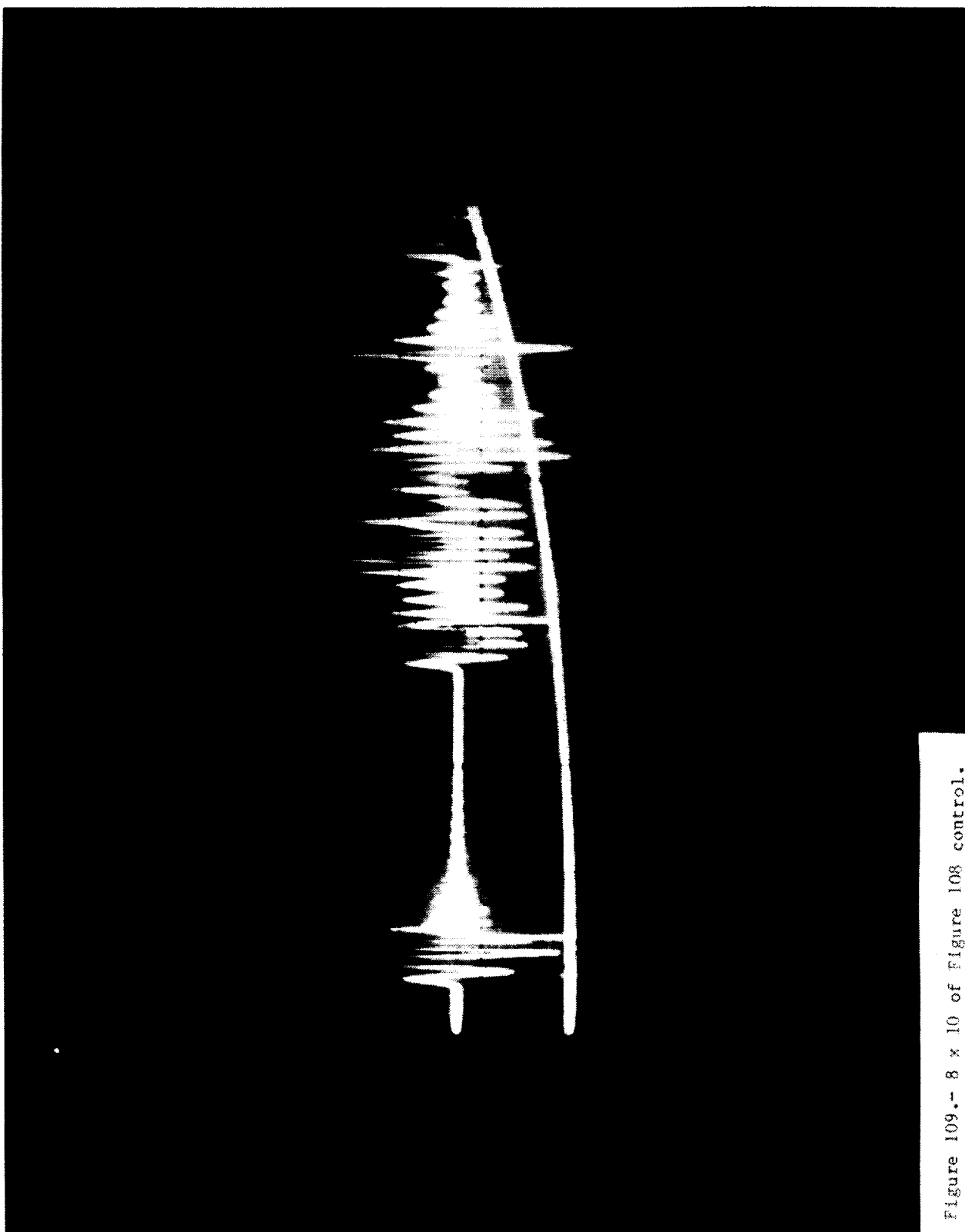
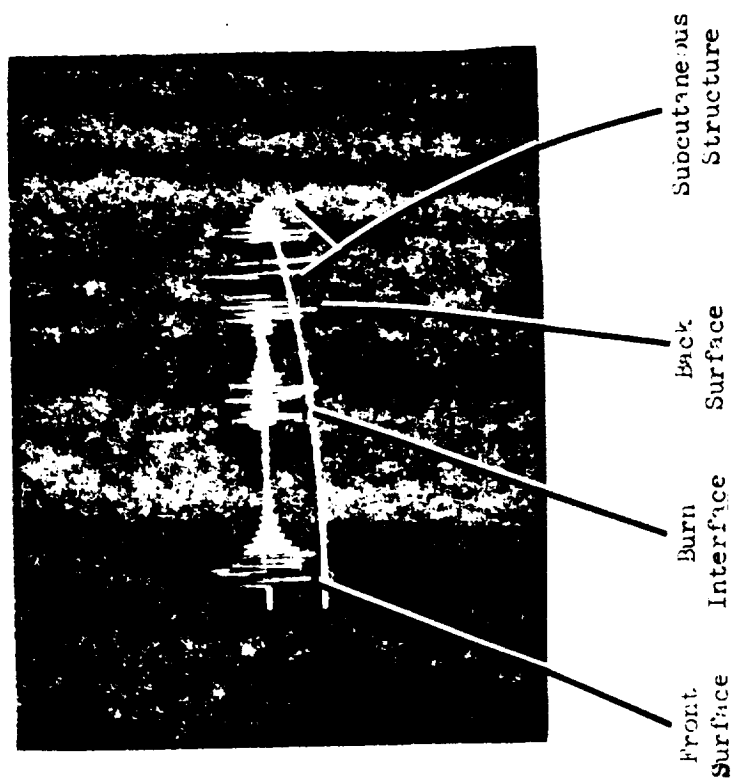


Figure 109.- 8 x 10 of Figure 108 control.



Right leg burn location 2 - 2nd degree 2/3 thickness

Skin thickness .90mm

Burn interface .65mm

M30W

Focused 15Mhz Xducer

Figure 110.- Control burn location 2.

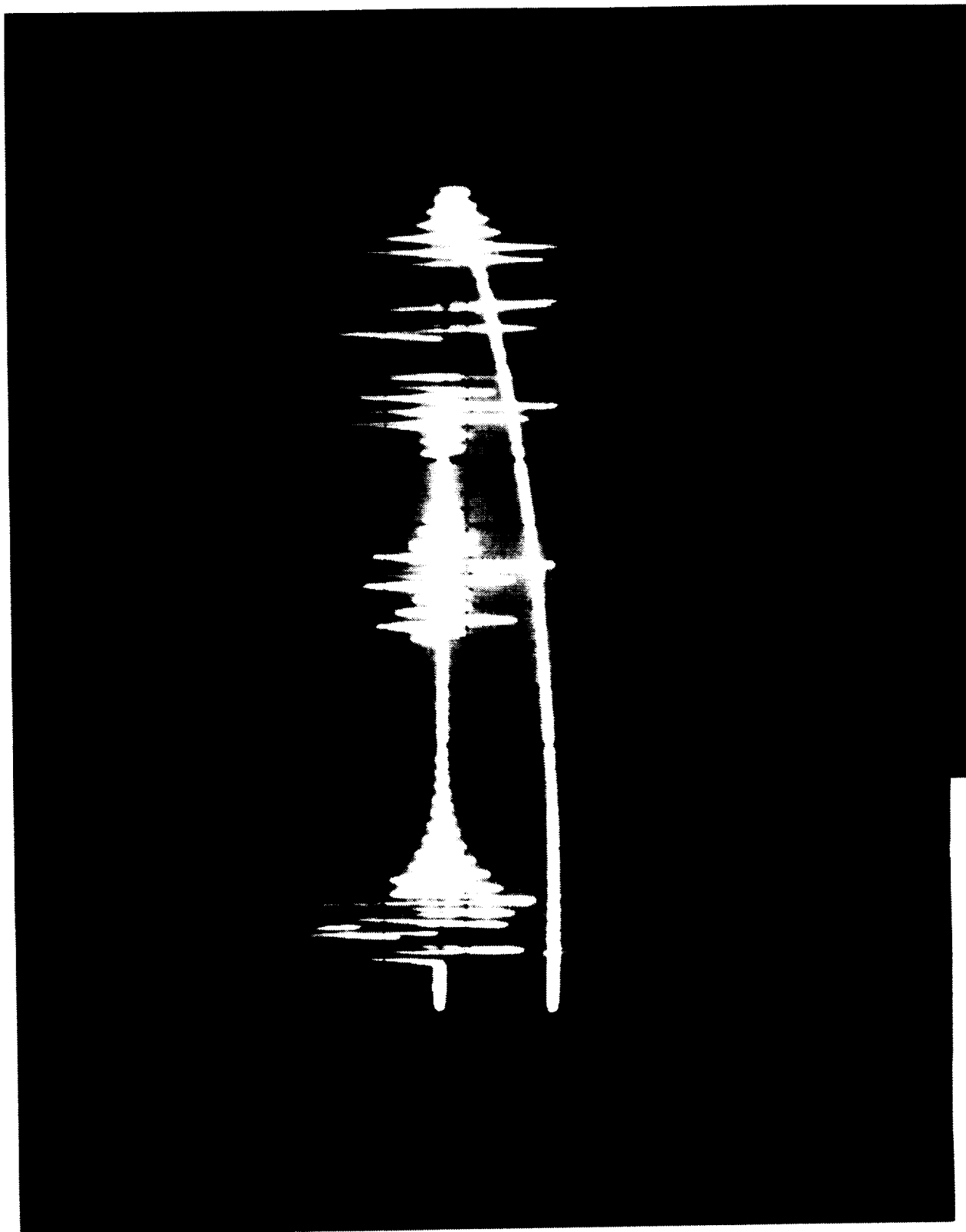
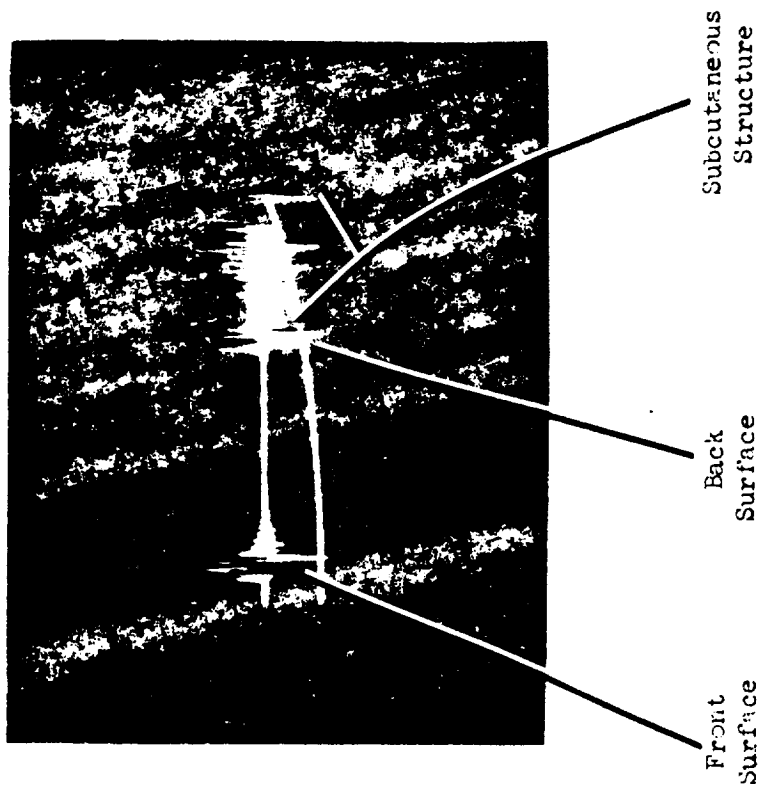


Figure III.- 8 x 10 of Figure 110 control.



Right leg area around burn location 2 - no burn

Skin thickness .80mm edema or change in sound velocity

M30W

Focused 15Mhz Xducer

Figure 112.- Right leg area around burn location 2.

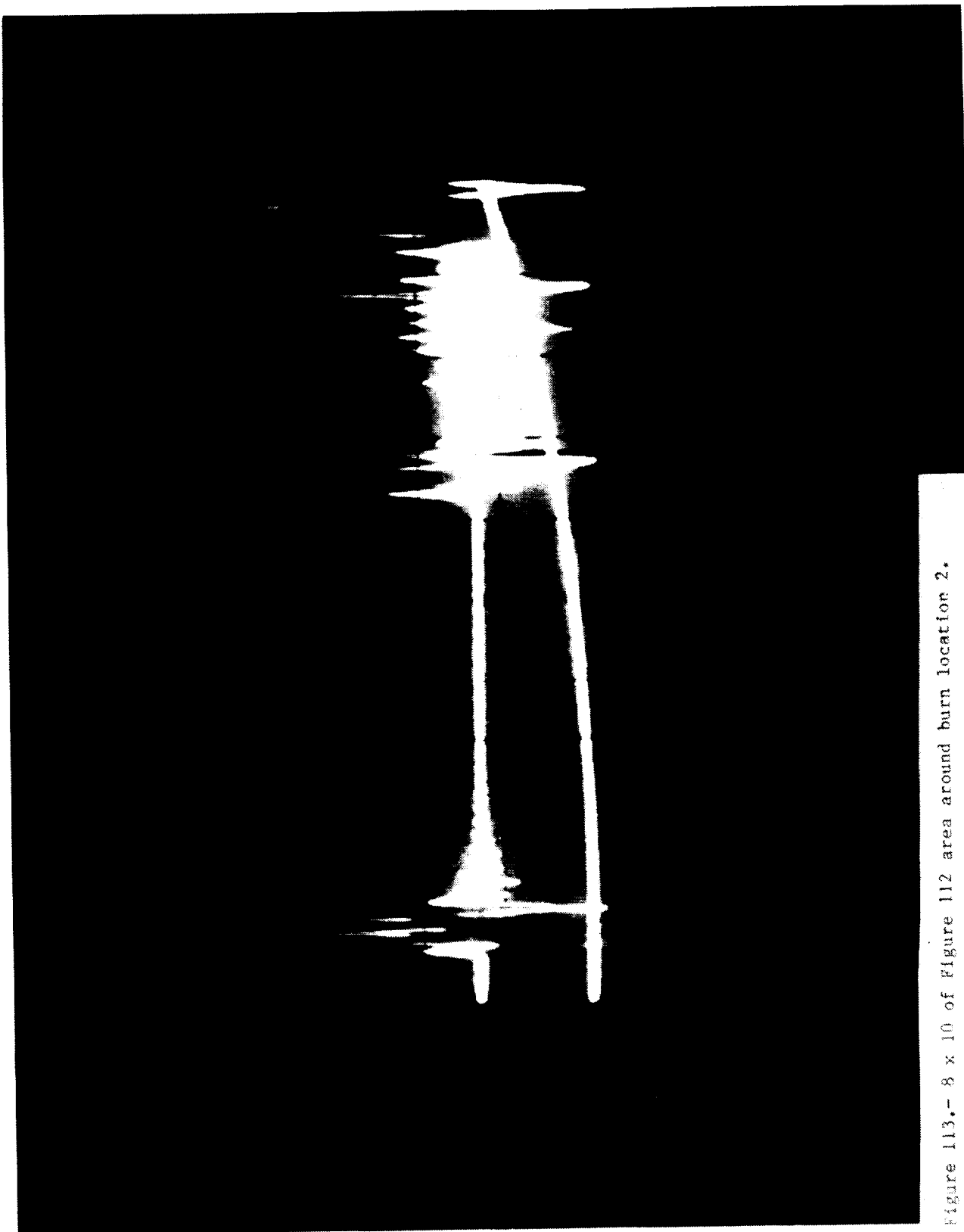
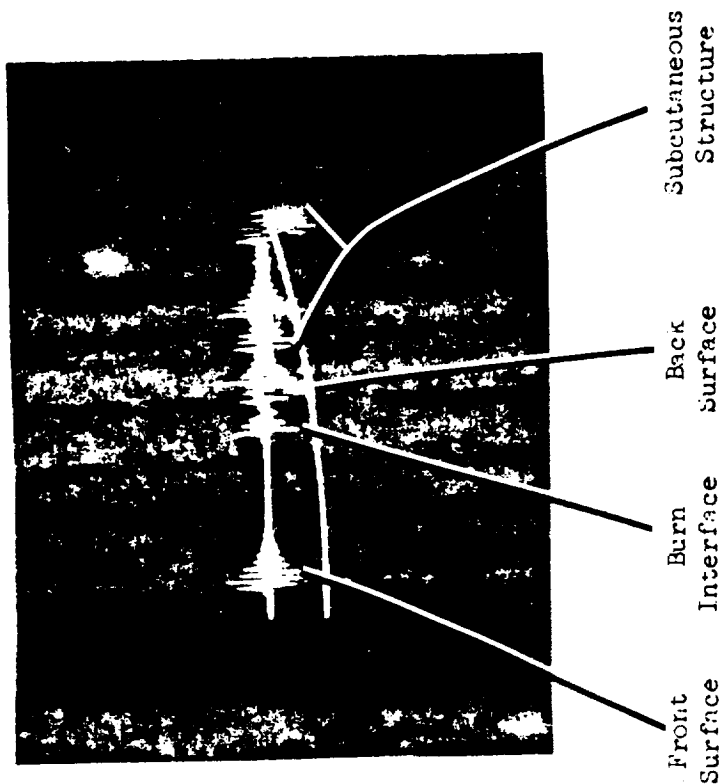


Figure 113.- 8 x 10 of Figure 112 area around burn location 2.



Right leg burn location 2 - deep dermal

Skin thickness .70mm slight edema or change in sound velocity

Burn interface .55mm

M30W

Focused 15Mhz Xcuser

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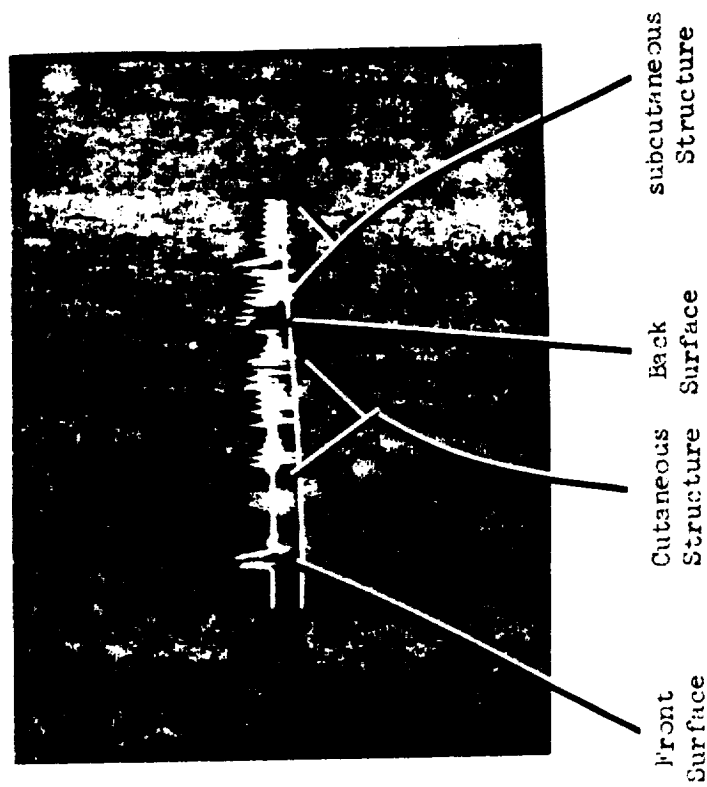
Figure 114.- Right leg burn location 2.



Figure 116.- 8 x 10 of bare locations.

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Control - location 1 (back)

Skin thickness .85mm

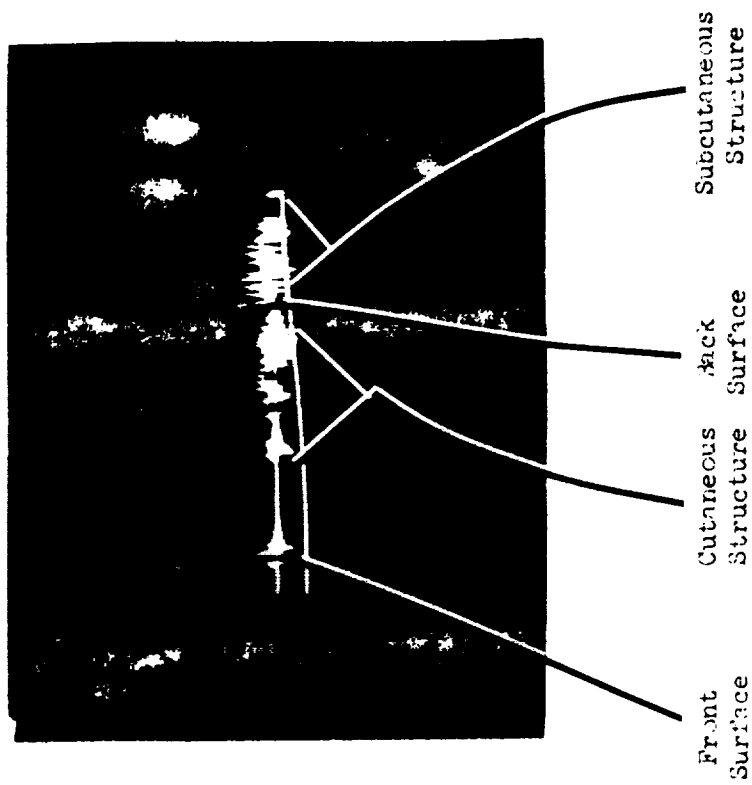
M57B

Focused 15Mhz Xducer

Figure 117.- Control location 1.



Figure 118.- 8 x 10 of Figure 117 control.



Control 2 location 1 (back)

Skin thickness .85mm

M57B

Focused 15Mhz Xducer

Figure 119.- Control location 1.

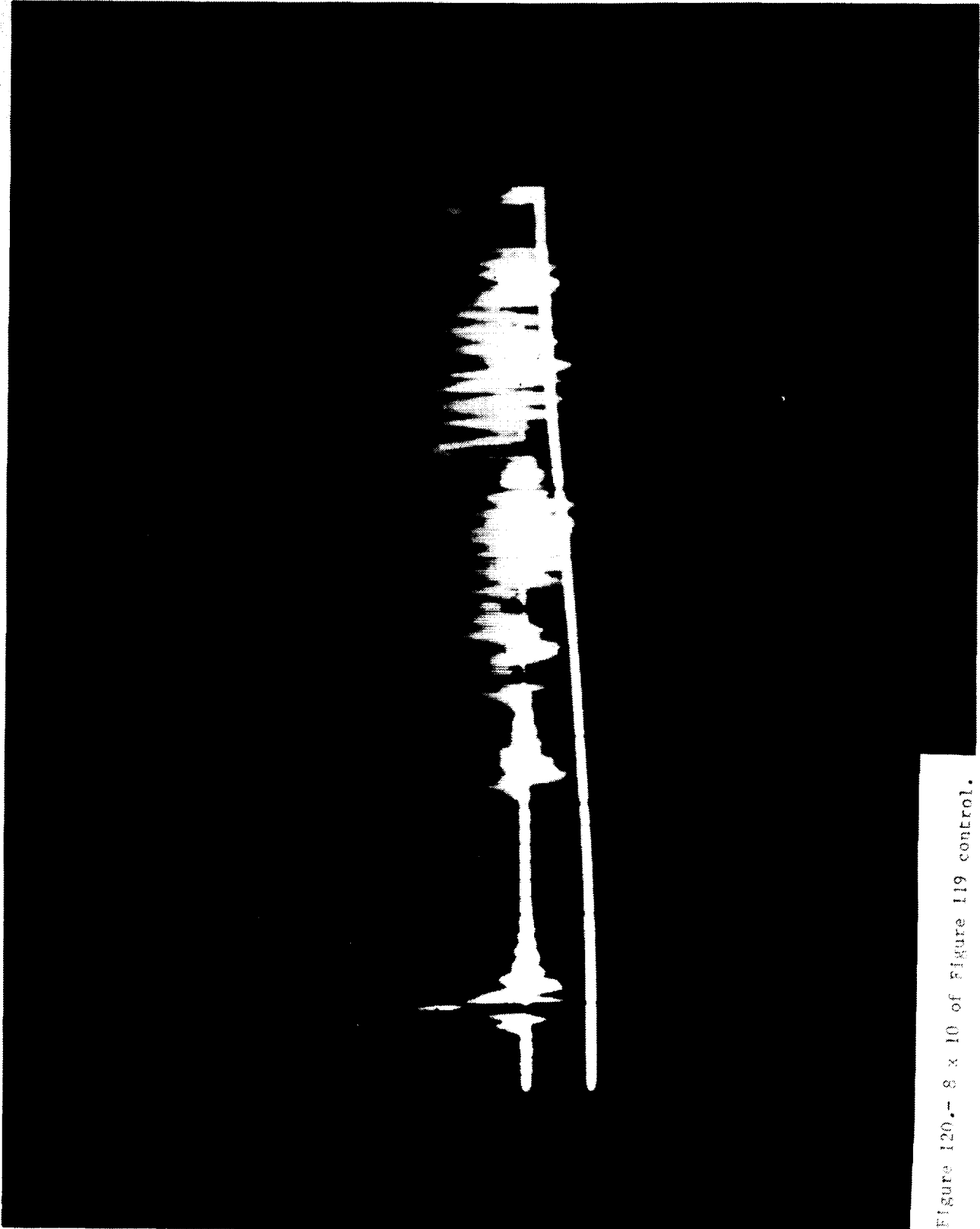
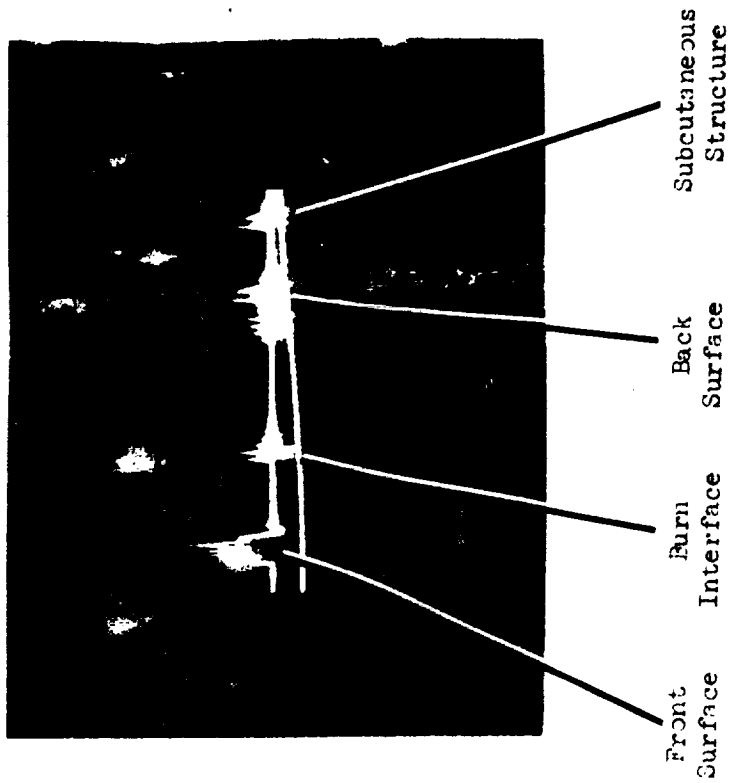


Figure 120.- 8 x 10 of Figure 119 control.

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Back location 1

Skin thickness .95mm edema or change in sound velocity

Burn interface .35mm

M57B

Focused 15Mhz Xducer

Figure 121.- Back burn location 2.

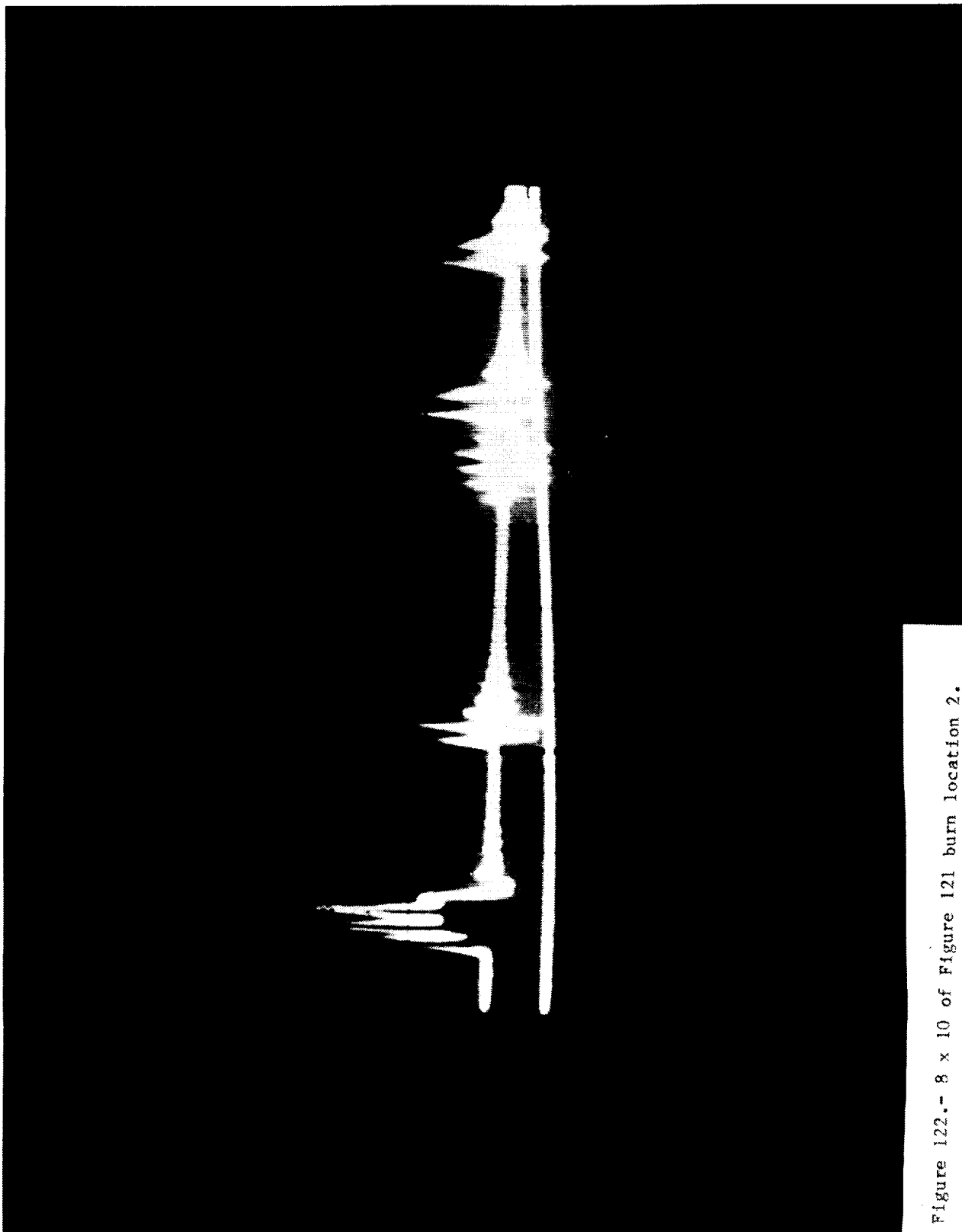
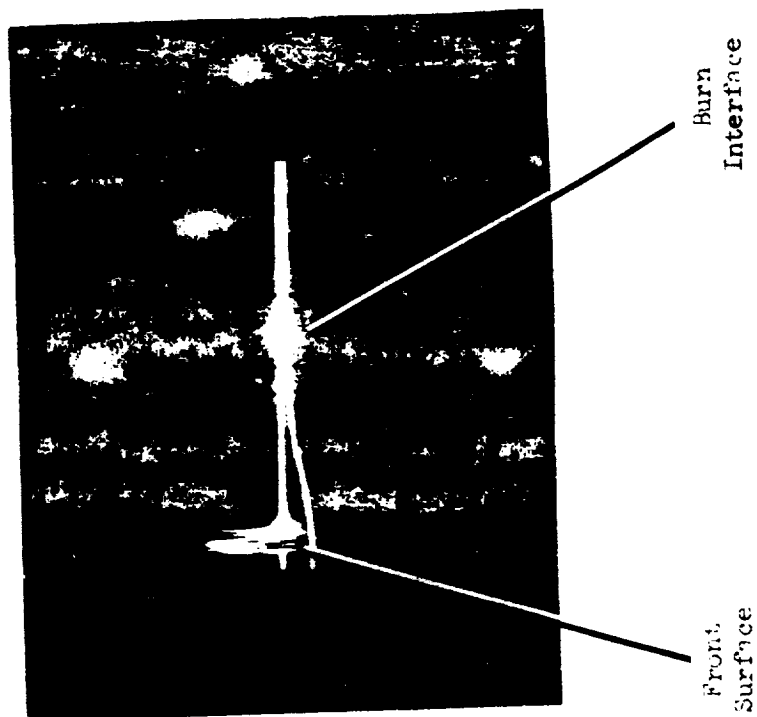


Figure 122.- 8 x 10 of Figure 121 burn location 2.

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Burn location 3 - full thickness

Burn interface .75mm

M57B

Focused 15MHz Xducer

Figure 123.- Back burn location 3.

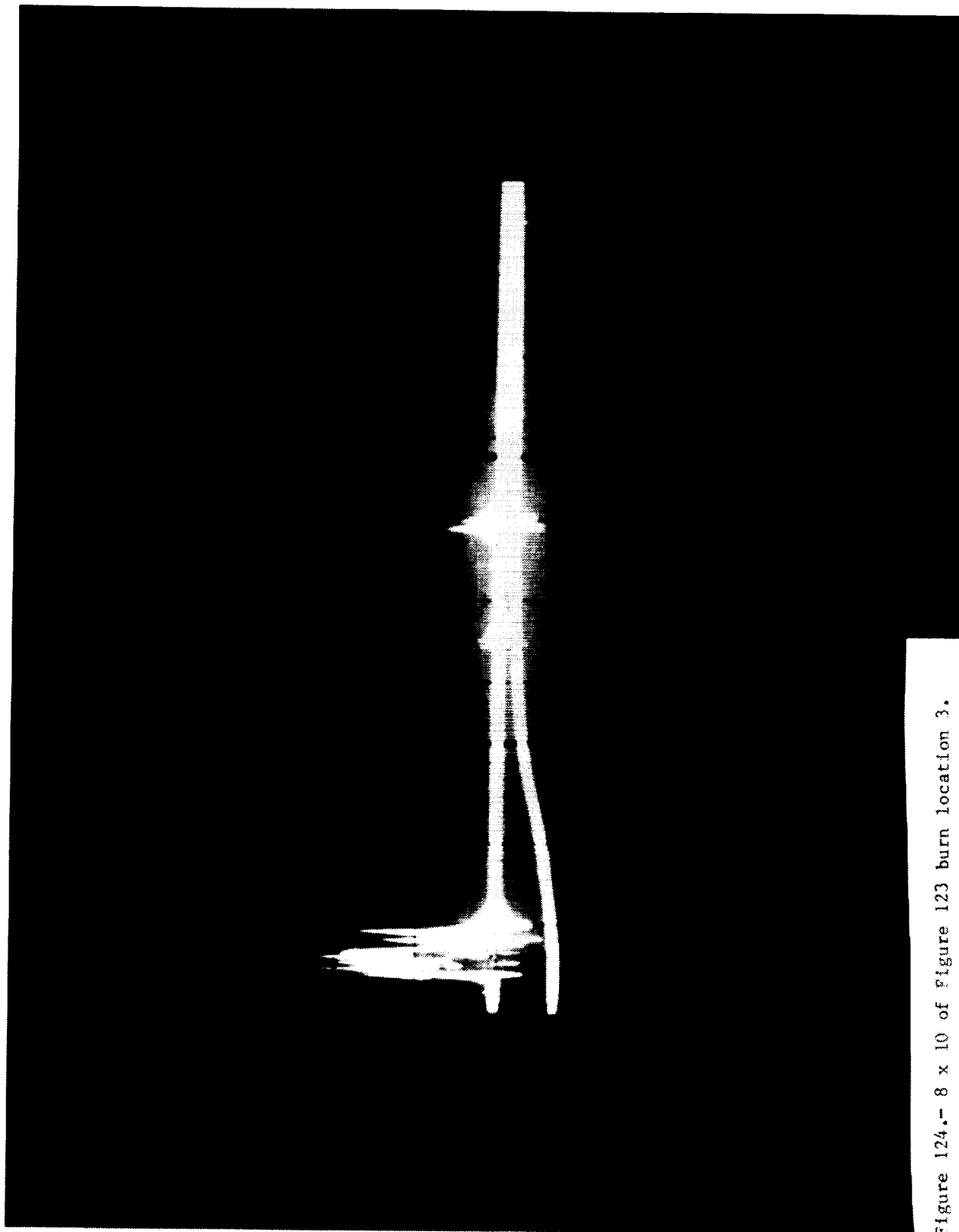
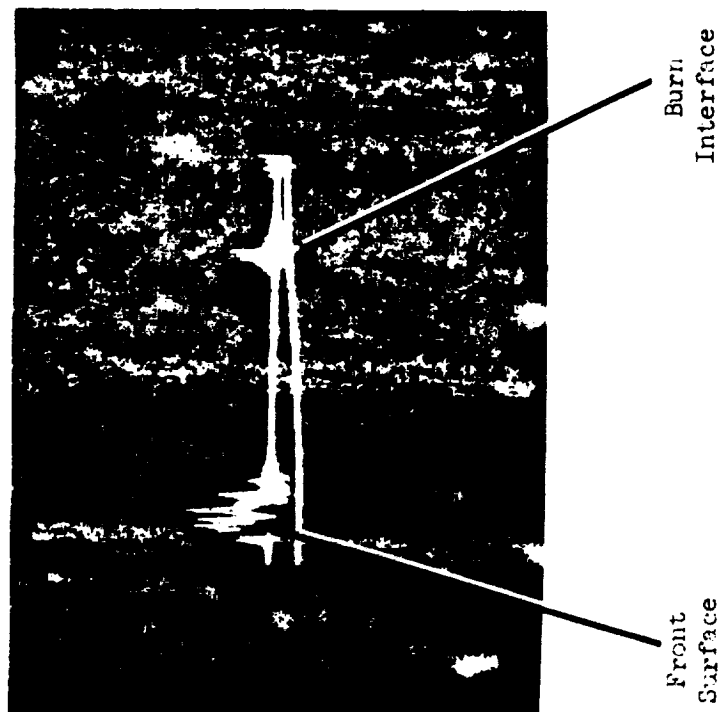


Figure 124.- 8 x 10 of Figure 123 burn location 3.

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Burn location 3 - full thickness

Burn interface .95mm edema or change in sound velocity

M57B

Focused 15Mhz Xducer

Figure 125.- Back burn location 3.

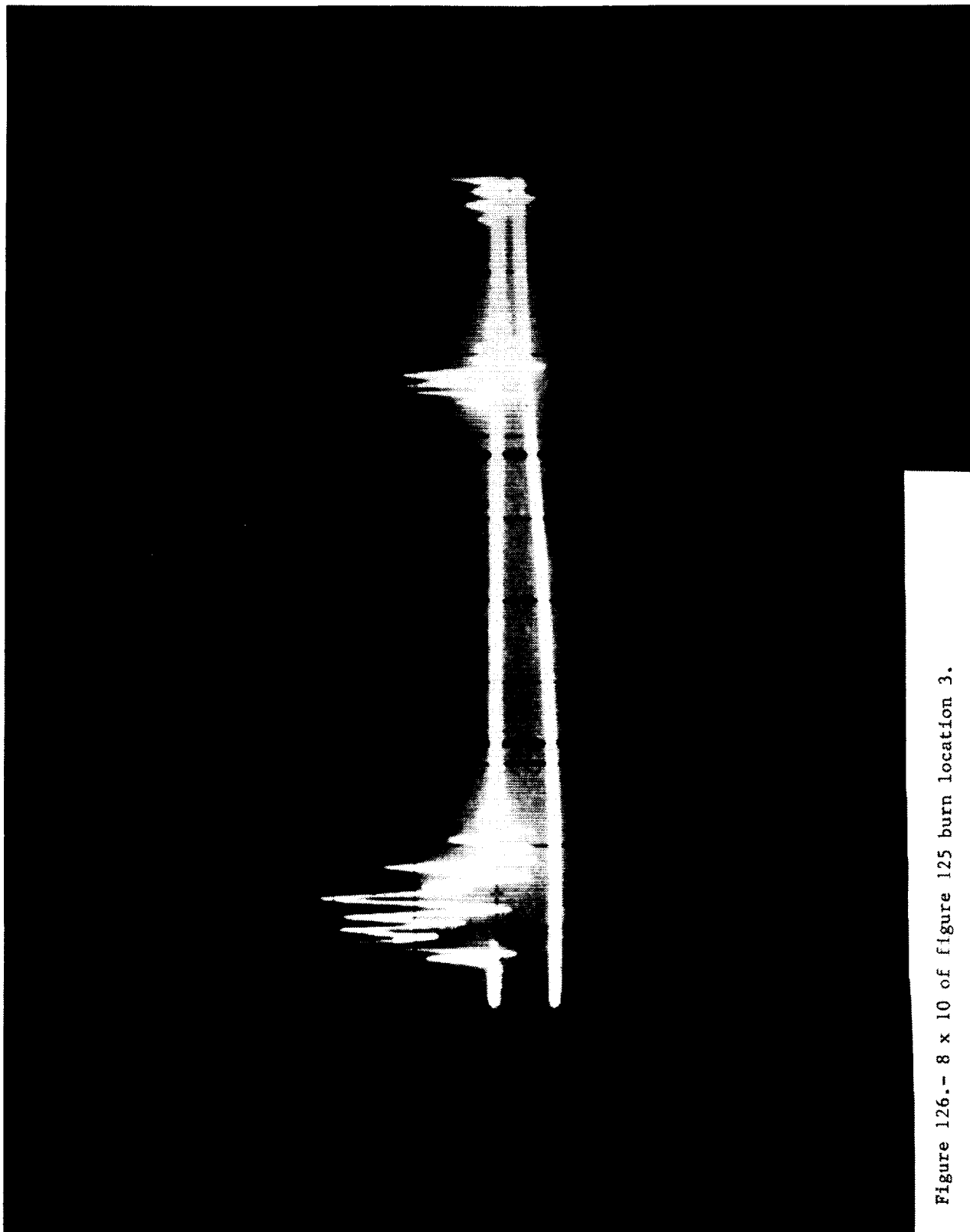


Figure 126.- 8 x 10 of figure 125 burn location 3.

APPENDIX B

Instrumentation

SUMMARY OF BURN INSTRUMENT OPERATION

For optimum response from the Burn Instrument set the controls as described below. Use a 15 MHz unfocused transducer.

| | | |
|----------------|----------------------|-----------------------|
| Oscilloscope | channel A volts/div. | 0.2v |
| | channel B volts/div. | 1.0v |
| | time/div | 0.2us |
| MR106 Receiver | gain (dB) | 56dB approx. |
| | Hi-Pass filter | 5MHz |
| | detector | on |
| | reject | 9-11 o'clock position |
| | filter | 7-11 o'clock position |
| TGC Amplifier | near gain | 9.85 approx. |
| | far gain | 3.2-4-4.0 approx. |

the operator aligns the 15 MHz transducer to optimize signal heights. This occurs when the transducer is perpendicular to the skin surface. When one has achieved a high first pulse and an equally high dermis/fat interface pulse the transducer is aligned and the TGC amplifier settings are correct. At this point the data may be stored using the foot switch marked store/display. (Movement of the transducer during the storage phase will most likely result in loss of data because of transducer misalignment.)

APPENDIX C

Animal Study Results
of Data from MCV

A COMPARISON OF ULTRASONIC DATA WITH HISTOLOGIC DATA

(Porcine Skin)

Burn Injury

| Ref. # | Time (us) | Thickness | Velocity ($\times 10^5$ cm/sec) |
|--------|-----------|-----------|----------------------------------|
| 4 | 1.64 | 0.804 | 0.98 |
| 5 | 0.24 | 0.77 | 6.42 |
| 7 | 1.16 | 0.524 | 0.90 |
| 7 | 1.16 | 0.563 | 0.97 |
| 8 | 1.42 | 0.577 | 0.81 |
| 11 | 0.12 | 1.40 | 23.33 |
| 12 | 0.32 | 0.393 | 2.46 |
| 12 | 0.32 | 0.242 | 1.51 |

Control

| | | | |
|---|------|-------|------|
| 1 | 1.30 | 1.12 | 1.72 |
| 2 | 1.44 | 1.49 | 2.07 |
| 3 | 1.52 | 1.64 | 2.16 |
| 6 | 1.52 | 0.702 | 0.92 |

RESULTS

Correlation Coefficient between time (ultrasonic measurements) and burn wound thickness (histologic measurements)

$$G_{xy}=0.92 \quad (\text{Data ref. \#5 and 11 discarded})$$

Velocity of Sound: $(\times 10^5 \text{ cm/sec})$

Necrotic Tissue:

$$1.27 \pm 0.63 \quad (\text{Data Ref. \#5 and 11 discarded})$$

Control:

$$1.72 \pm 0.56$$

Velocity of Sound, previous measurements on porcine skin, necrotic and viable tissue $(\times 10^5 \text{ cm/sec})$

$$1.72 \pm 0.045$$

Discussion

Velocity.- After matching the appropriate times with the thickness of the burn injury and the control measurements, the velocity of sound was calculated for each time-thickness data pair. Examination of these values led to the exclusion of Ref #5 and 11, as these were clearly unrealistic. The rest of the velocities were averaged, and the results are given. For reference, other measurements in porcine skin are also listed [from Goans, Cantrell and Meyers, Medical Physics 4,259 (1977)].

Agreement between these determinations and those taken earlier are quite good for the control set, which we think is the same as listed for viable tissue. However, there is significant difference between the value just obtained from necrotic skin and that obtained earlier. The earlier study shows no significant difference in velocity for both viable and necrotic skin tissue. We believe that the determination of the velocity of sound in necrotic tissue is too low, as it is lower than for any soft tissue known to us.

If one assumes that the sound velocities for both necrotic and viable tissue are the same, then one can calculate the shrinkage of necrotic tissue necessary for the results determined above. If the shrinkage of the necrotic tissue were 27 percent, then the results of these measurements can be brought in line with that obtained by the earlier study. It should be noted, however, that the shrinkage is selective, since it was not apparent in the control measurements. Hence, it appears as if only the burn-necrotic portions of the samples shrank during the processes associated with the histologic measurements.

Correlation between burn thickness (histologic) and ultrasonic time interval between reflections from the skin surface and the burn-viable skin interface.-

After eliminating the two data pair as outlined above, we evaluated the correlation coefficient from the remaining data (burn depth vs. time). Its value is:

$$G_{xy} = 0.92$$

Specimen preparation and staining for the histologic measurements used in the earlier burns study

Upon excision, the specimen was fixed immediately by immersion in an isotonic Millonig's phosphate buffer containing 0.1 percent EDTA, 3 percent sucrose, and 0.5 percent glutaraldehyde at pH 7.4. After several days fixation, the tissue was stained with Verhoeff's elastica stain and with Van Gieson's counterstain.

The advantage of this is that it was felt that it produced only negligible alteration of the tissue. Moreover, it also gave a clear, visible differentiation between the necrotic and the viable tissue.

APPENDIX D

Loading Gel into Sterilized Delay Line
Column

Loading the Gel-filled Sterilized Delay Line Column (SDLC)

Purpose of the column.- Because of the success of using the gel-filled sterilized delay line column (SDLC), we decided to put a rather complete section on preparation and use of it. From the standpoint of acoustics, the purposes of the SDLC are

(1) to provide a transmission medium in which ultrasound can travel to and from the burn wound, (2) to provide within the medium for the sound waves to come to focus in the wound itself, and (3) to provide for proper alignment of the transducer and the wound for optimum reception of echoes. From the standpoint of the electronics of the instrumentation, the additional travel time of the ultrasound in the SDLC allow the input preamplifiers time to recover from the overload caused by electrical excitation of the transducer.

We used sterile techniques as we loaded the gel into the column. Since all who are reading this for use will be familiar with sterile techniques, we will not discuss it here. Please, however, keep in mind that the wounds that will be investigated with this are susceptible to infections, and that serious harm might be done to the patient if a contaminated probe is used.

The gel used to fill the column was "Surgilube" sterile bacteriostatic gel, manufactured by E. Fougera and Co. (a division of Altana, Inc.), Melville, New York 11747. It was supplied in sealed packets. Each packet contained 0.5 gm, and was found to contain enough gel to adequately fill one column.

It is best to store the gel packets in the upright position, with the tear line at the top. In this position most of the air bubbles will work their way out of the gel prior to its use. Also, when loading into column, try to continue its upright position.

Preparation of packet and the transducer.- The delay line columns were sterilized prior to use by radiation from a radioactive source. We used sterile technique throughout the loading procedure and use. The packet was grasped at the top near the tear line. Similar to shaking mercury down into a thermometer, the gel was shaken down to the lower part of the packet. Using pressure between two fingers, any additional gel in the top was squeezed down to the gel pool in the packet. The gel packet from the top to well below the top of the gel pool was wiped with alcohol before opening.

The transducer cannot be autoclaved. Nor is it wise to irradiate it. We recommended that its surface and head be cleaned and sterilized by scrubbing it in isopropyl or ethyl alcohol.

- Cut or tear packet close to the top of the gel pool (just above the top of the gel)
- Push in from sides to make opening as nearly circular as possible
- Squeezing from the bottom of the packet, load gel into tube. Make sure that no air bubbles are in the column. Such bubbles can induce reflections that cause false triggering of the instrument. If some air bubbles get into the column, push in additional gel until all bubbles are moved out the top of the SDLC. When finished, there should be a convex

surface of gel at the top of the transducer, against which the transducer head will fit.

- Angle the head of the transducer and make contact against the gel at the top of the SDLC. If there is excess gel, push it aside with the transducer head. The important point is to make certain that the transducer head is in contact with the gel (no air bubbles at the interface of the transducer head and the gel). Slide transducer head into SDLC until it seats against the lip in the SDLC. Lightly tighten the thumb screw on the SDLC to secure it on the transducer.

The transducer with the SDLC is now ready to use. When using, be certain that the transducer-SDLC is perpendicular to the wound surface. This assures that the ultrasonic reflections of interest will be properly received by the transducer.

APPENDIX E

Future Directions



Figure 129.- Photograph of the prototype burns instrument. The top trace on the oscilloscope shows the front and back surface of skin.



Figure 130.- A photograph of surgical lubricant pack
used with the delay column.

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67-8117

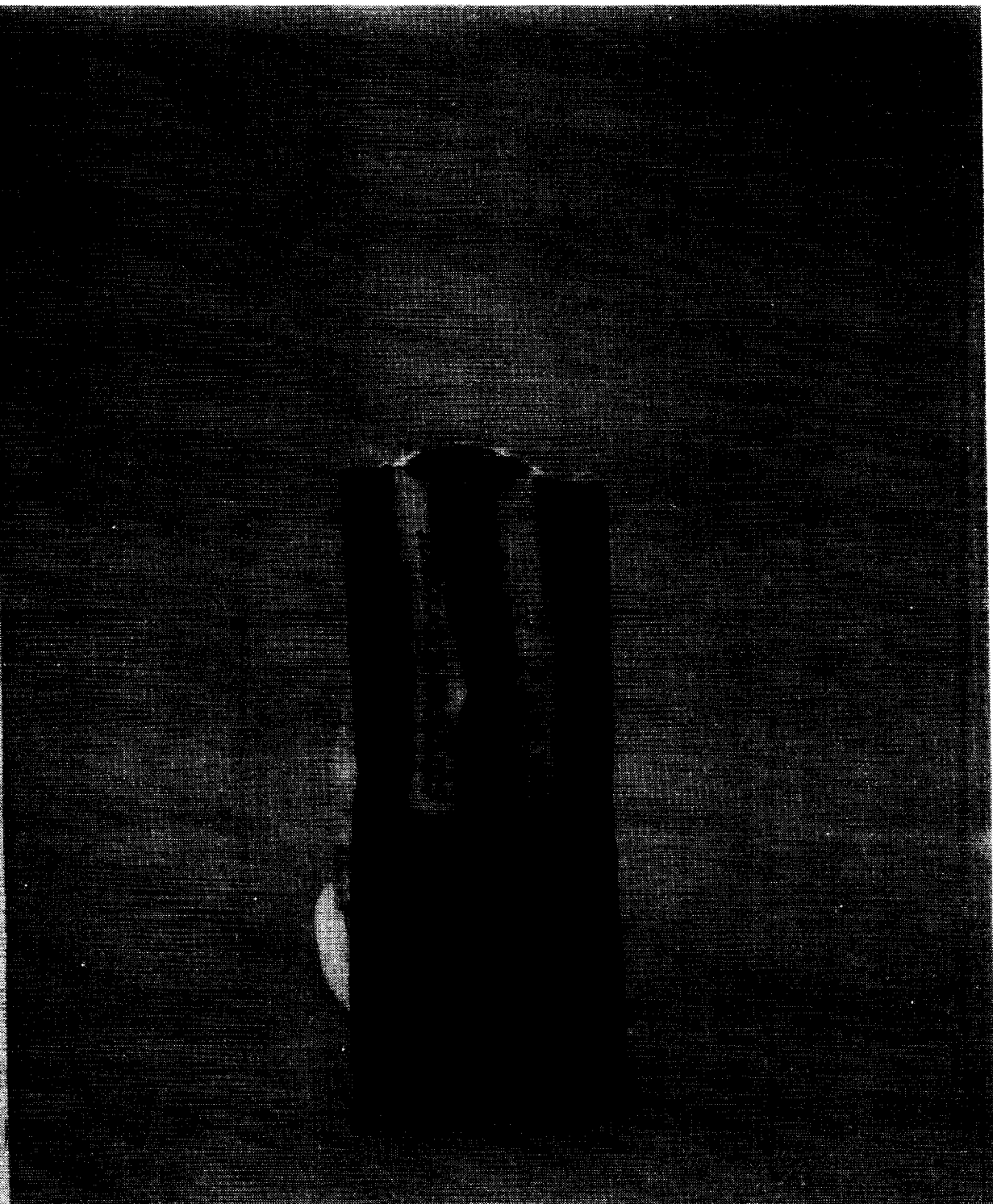


Figure 131.- Photograph of gel pack, opened, with top flanged for loading column.

NASA

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Figure 132.- Photograph of gel being loaded in column.

L-87-8185

NW5A

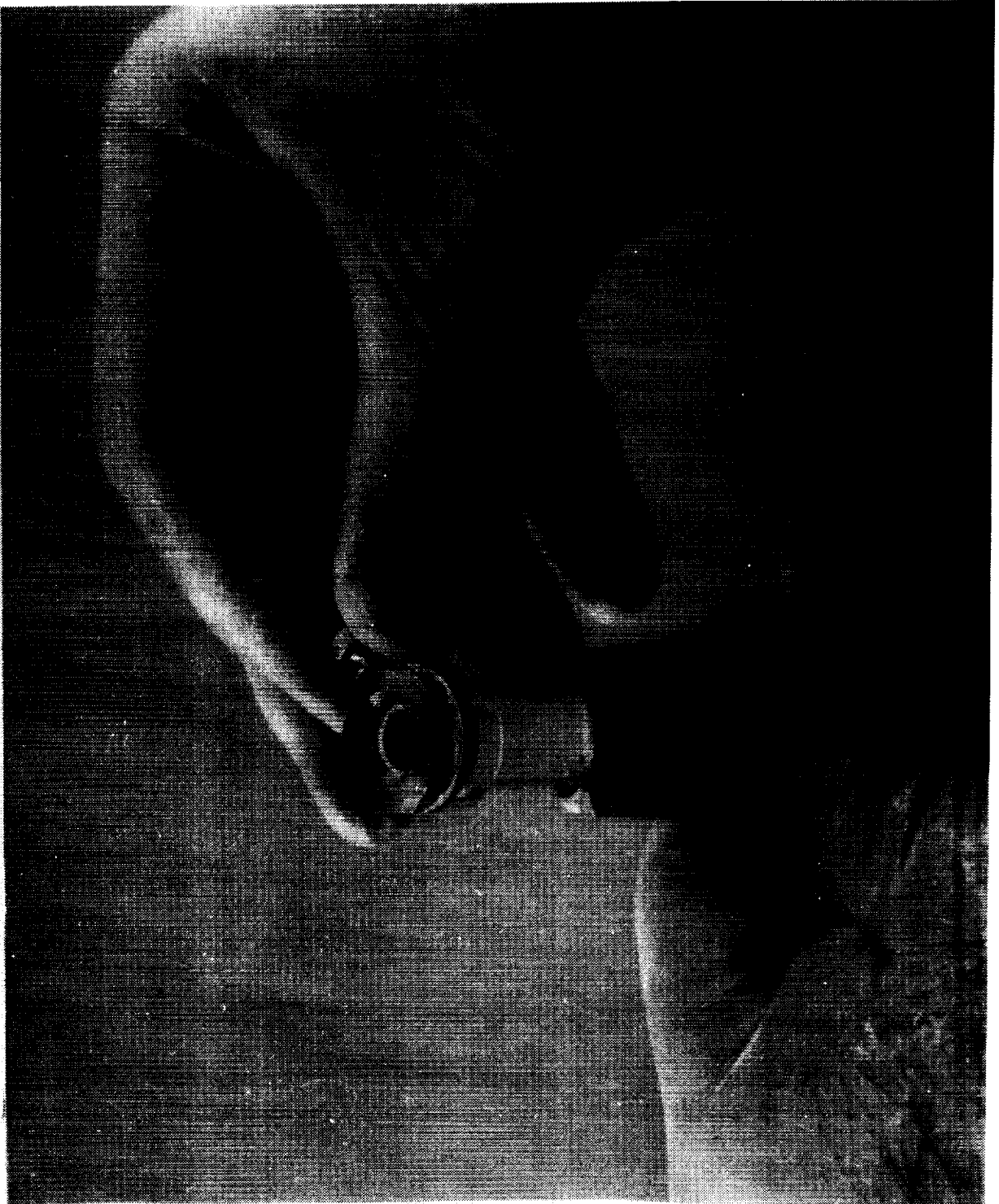


Figure 133.- Photograph of gel loaded into column.
Note the convex surface on the top of
the column.

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NASA



Figure 134.- Transducer used in the burns study.

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NASA



Figure 135.- Photograph showing the attachment of the transducer to the column. Care must be exercised to prevent an air bubble between the gel and the transducer face.

NASA

87-8180



Figure 136.- Photograph showing the position of the transducer-gel column assembly for a measurement. Notice that the assembly is positioned perpendicular to the skin surface.

Future Directions

This area of the report will obviously take on an emphasis that strongly depends on the background and interests of the persons who are writing it. Since the report is coming from the group at NASA Langley Research Center, it is going to reflect rather strongly the areas needing quantitative data that was unavailable at the time that we designed the instrument. (We did the best that we could by extracting from some early works on animals and some sketchy data on humans, and extrapolating to frequencies used in this design. But at times, the lack of data was unnerving to the designer!) It will also stress those areas of theory prediction that we believe need to be tested.

Sorely needed in the area are velocity and attenuation data, including its frequency dependence on human skin as a function of age, sex, race, health, etc. This would help in making the apparatus more quantitative as a diagnostic tool for burn depth measurement, as it would establish norms against which pathological states can be compared.

Another unresolved issue is the velocity and attenuation of necrotic skin tissue. This measurement was thwarted, even in the animal studies done at MCV, by the apparent shrinkage of the histological sections. (Recall that the staining and fixing technique used in the Oak Ridge study did not show the same shrinkage characteristics as that used at MCV.) This is a puzzle to us, and we think that it is worthy of some more attention--either to confirm the shrinkage difference in the staining and fixing techniques used in the two studies, or to show that the technique used in the Oak Ridge study truly did preserve sample dimensions, as asserted in the publications.

In the literature search, we discovered a paper that related the velocity of ultrasound to the percent of collagen in tissue. It appears that this might provide some insight into the aging process in skin in that if the assertion is correct for human skin, it might provide some help in diagnosing maladies which affect percent of collagen in skin. One would need another way of measuring the thickness of skin in order to determine the velocity of ultrasound, such as x-rays.

With the ultrahigh resolution available with this instrument, it may be possible to use it with a systematic study of pathological states of skin, such as tumors, etc. It could also be used to study effects of ultraviolet rays on skin. Perhaps such a study could lead to a better understanding of the role of UV radiation in the formation of skin cancer.



Report Documentation Page

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|--|--|--|---|---|--|
| 1. Report No. NASA TM-104116 | | 2. Government Accession No. | | 3. Recipient's Catalog No. | |
| 4. Title and Subtitle An Ultrasonic Technique to Measure the Depth of Burn Wounds in Humans | | | | 5. Report Date June 1991 | |
| | | | | 6. Performing Organization Code | |
| 7. Author(s) William T. Yost John H. Cantrell Pamela D. Hanna | | | | 8. Performing Organization Report No. | |
| | | | | 10. Work Unit No. 141-20-40-05 | |
| 9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225 | | | | 11. Contract or Grant No. | |
| | | | | 13. Type of Report and Period Covered Technical Memorandum | |
| 12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001 | | | | 14. Sponsoring Agency Code | |
| | | | | | |
| 15. Supplementary Notes William T. Yost and John H. Cantrell: Langley Research Center, Hampton, Virginia. Pamela D. Hanna: Analytical Services & Materials, Inc., Hampton, Virginia. | | | | | |
| 16. Abstract Whenever ultrasound encounters a discontinuity in its medium of propagation, some energy is reflected from the interface. Such reflections or "echos" occur when incident energy encounters the front skin, viable/necrotic, and dermis/fat skin tissue interfaces. It has been shown that the most probable cause of the viable/necrotic interface is the uncoiling of collagen in the necrotic tissue, which can cause a reflection at the viable/necrotic interface of approximately 10 percent of the wave amplitude, and is approximately the same as that from the other two interfaces noted. This instrument, still in the prototype stage, was designed to detect the various reflections from within the skin layer. It is shown that, by studying the timing between the various "echos," one can use ultrasound as an aid in diagnosing the depth of burned skin tissue in humans. The instrument is a 60 MHz A-scan unit, modified to more easily identify the echos occurring within the short time interval during which the reflections are received from the skin layers. A high frequency unit was selected so that various transducers could be utilized to optimize the system. Signal conditioning circuits were modified and added to provide an adequate display of the principle reflections expected. The unit was successful in studying burned tissue in pigs and has more recently been used to study burn wounds in humans. Measurement techniques and preliminary results are presented. The work presented here is based on efforts through 1987. | | | | | |
| 17. Key Words (Suggested by Author(s)) Ultrasonic A Scan Exponential Time Gain Compensation Burns Wound Depth Measurement Scald Burn Flame Burn Chemical Burn | | | 18. Distribution Statement Unclassified - Unlimited Subject Categories 33, 51, 71 | | |
| 19. Security Classif. (of this report) Unclassified | | 20. Security Classif. (of this page) Unclassified | | 21. No. of pages 163 | |
| | | | | 22. Price A08 | |